National Library
of Canada

Acquisitions and
Bibliographic Services

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale
du Canada

Acquisisitons et
services bibliographiques

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence
ISBN: 0-612-87885-6
Our file Notre référence
ISBN: 0-612-87885-6

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou aturement reproduits sans son autorisation.

Canadä

University of Alberta

Library Release Form

Name of Author: Rashmi Priya Sinha

Title of Thesis: Analysis of Salt Movement in Capped Composite Tailings and it's Effects on Plant Growth

Degree: Master of Science

Year this Degree Granted: 2003

Permission is hereby granted to the University of Alberta Library to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly or scientific research purposes only.

The author reserves all other publication and other rights in association with the copyright in the thesis, and except as herein before provided, neither the thesis nor any substantial portion thereof may be printed or otherwise reproduced in any material form whatever without the author's prior written permission.

Date: July 31, 2003

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled 'Analysis of Salt Movement in Capped Composite Tailings and its Effects on Plant Growth' by Rashmi Priya Sinha in partial fulfillment of the requirements for the degree of Master of Science in Soil Science.

Dr. Carl Mendoza

Date: 31-07-03

Abstract

Composite tailings (CT) are produced as a measure to reduce the volume of oil sand tailings by accelerating self-weight consolidation. Water released in the process is known as CT water, which is saline, making the reclamation of CT for revegetation difficult. A growth chamber study was conducted to monitor the effect of saline CT water on the growth of dogwood (*Cronus stolonifera*. Michx.), and highlander grass (*Elymus trachycaulus* subsp. *Trachycaulus*), and to determine the suitable thickness of an unsaturated tailings sand cap separating CT water and the surface reclamation material. Eighteen columns were constructed, each of 56 cm in diameter and 100 cm in height. Each column was filled with tailings sand to a depth of 65 cm and then capped with 30 cm of reclamation material consisting of soil and peat mix. Constant CT water levels at 0, 30, and 60 cm from the soil/sand interface were maintained throughout the experiment. Dogwood and highlander grass were grown in these columns for one year. Tap water was applied at 3 mm (low) and 6 mm (high) every alternate day to dogwood, and every third day to highlander grass to simulate the dry and the wet conditions respectively. Treatments receiving low irrigation showed significant increase in the salt content in the sand cap in one year. During the drought period, access to the saline CT water kept the plants alive for 66 days in the growth chamber condition. CT water level at 60 cm below the soil/sand interface prevented the accumulation of salt in the rooting zone. Based on the shoot dry weight data, highlander grass was found to be more salt tolerant than dogwood.

Dedication

To my husband Hemant Kumar
and
my parents S.N.Sinha and Dr. R.K.Sinha
whose love and support helped me to become a better person

To Kushagr and Ishita

Acknowledgements

I would like to thank:

Dr. Yongsheng Feng for his valuable advice and his support throughout my studies

Dr. W.B. McGill, and Dr. M. J. Dudas for their guidance

Dr. S. Abboud (ARC, Edmonton) for keeping my moral up throughout my study

Dr. X. Lee and J. Strorey (ARC, Vegreville) for helping with root analysis

Dr. C. Qualizza (Syncrude Canada Ltd, Fort MacMurray) for her valuable suggestion

Dr. Wije Bandarnaike, Dr. F. Zeinedidn, Ben, M. Ayala, Lynette, C. Figueiredo, Dick Purveen, and Bruce for their valuable technical assistance

Syncrude Canada Ltd. for financial support

Special thanks to my husband Mr. Hemant Kumar for his constant love and support throughput my study

Dr. S. Varma for his support

Table of Contents

CHAPTER - 1

INTRODUCTION 1
- *1.1. Background* *1*
- *1.2. Oil recovery process* *1*
- *1.3. Tailings sand* *2*
- *1.4. Fine tailings and mature fine tailings (MFT)* *2*
- *1.5. Management of mature fine tailings* *3*
- *1.6. Composite tailings (CT)* *4*
- *1.7. Rationale of the study* *5*
- *1.8. Objective* *6*
- *1.9. Thesis outline* *7*
- *1.10. References* *13*

CHAPTER - 2

LITERATURE REVIEW 17
- *2.1. Introduction* *17*
- *2.2. Composite tailings* *17*
- *2.3. Measurement of soil salinity* *18*
- *2.4. Movement of salt in soil* *18*
- *2.5. Leaching of excess salt* *20*
- *2.6. Salinity and soil-plant water relations* *21*
- *2.7. Specific ion toxicity* *22*
- *2.8. Nutritional effects* *23*
- *2.9. Effect of salinity on photosynthesis* *24*
- *2.10. Salinity and growth* *25*
- *2.11. Salt Tolerance* *26*
- *2.12. Summary* *27*
- *2.13. References* *28*

CHAPTER - 3

METHODOLOGY 38
- *3.1. Experimental Setup* *38*
- *3.2. Treatments* *39*
- *3.3. Analyses* *42*
- *3.4. References* *50*

CHAPTER - 4

ELECTRICAL CONDUCTIVITY AND SALT DISTRIBUTION IN CAPPED COMPOSITE TAILINGS 51
- *4.1. Introduction* *51*
- *4.2. Materials and methods* *52*
- *4.3. Results* *53*
- *4.4. Discussion* *58*
- *4.5. Conclusion* *62*
- *4.6. References* *74*

CHAPTER – 5

INFLUENCE OF SALINE PROCESSING WATER ON PLANT WATER RELATIONS OF DOGWOOD (*CRONUS STOLONIFERA*. MICHX.) AND HIGHLANDER GRASS (*ELYMUS TRACHYCAULUS* SUBSP. *TRACHYCAULUS*) 76
- *5.1. Introduction* *76*
- *5.2. Materials and methods* *78*
- *5.3. Results* *79*

5.4. *Discussion* *83*
5.5. *Conclusion* *86*
5.6. *References* *96*

CHAPTER - 6

IMPACT OF COMPOSITE TAILINGS WATER ON PHOTOSYNTHESIS AND GROWTH OF DOGWOOD (*CRONUS STOLONIFERA*. MICHX.) AND HIGHLANDER GRASS (*ELYMUS TRACHYCAULUS SUBSP. TRACHYCAULUS*) 100
6.1. *Introduction* *100*
6.2. *Materials and methods* *102*
6.3. *Results* *104*
6.4. *Discussion* *109*
6.5. *Conclusion* *113*
6.6. *References* *129*

CHAPTER - 7

SYNTHESIS 135
7.1. *Major findings* *136*
7.2. *Implications* *137*
7.3. *Recommendation* *138*
7.4. *Future study* *139*
7.5. *References* *140*

APPENDIX A1 .... **142**

List of Tables

Table 1.1 Properties of tailings sand and composite tailings 12
Table 3.1. Distribution of treatments 49
Table 4.1. Physical and chemical properties of CT water, tailings sand and the reclamation material. 68
Table 4.2. Electrical conductivity of the soil pore water collected in the early period of the experiment (first 3 months) 69
Table 4.3. Electrical conductivity of the soil pore water Collected in the early period of the experiment (next 3 months) 70
Table 4.4. ANOVA summary for the EC analysis of the samples collected from three depths of dogwood and highlander grass at the end of the experiment. 71
Table 4.5. Amount of CT water used by dogwood and highlander grass during the experiment. 72
Table 4.6. Soil compaction in treatment with highlander grass 73
Table 5.1. Water potential of dogwood and highlander grass recorded in the early period of the experiment 92
Table 5.2. Osmotic potential of dogwood and highlander grass recorded in the early period of the experiment 93
Table 5.3. Turgor potential of dogwood and highlander grass recorded in the early period of the experiment 94
Table 5.4 ANOVA summary for WP and OP of dogwood and highlander grass during short drought period (drought period 1) and long drought period (drought period 2). 95
Table 6.1 ANOVA summary for the photosynthesis data of dogwood and highlander grass in the first drought and second drought periods. 126
Table 6.2. ANOVA summary for shoot dry weight and root dry weight, root length, root volume, and leaf area of dogwood and highlander grass. 127
Table 6.3. Shoot : Root ratio of dogwood and highlander grass 128

List of Figures

Figure 1.1. Mine sites where Syncrude Canada Ltd. is located. 8

Figure 1.2. Schematic diagram of the oil recovery process and the production of composite tailings (CT). 9

Figure 1.3. Arial view of the Mildred lake settling pond at Syncrude in Fort Mc Murray. 10

Figure 1.4. Schematic diagram of the proposed reclamation technology. 11

Figure 3.1. Experimental set up of the column. 48

Figure 4.1. Electrical conductivity of the soil pore water collected from the soil layer of treatment with dogwood and highlander grass during the drought periods. 63

Figure 4.2. Electrical conductivity of the soil pore water collected from the soil/sand interface of treatment with dogwood and highlander grass during the two drought periods. 64

Figure 4.3. Electrical conductivity of the samples collected at the end of the experiment from the three depths of treatment with dogwood and highlander grass. 65

Figure 4.4. Salt distribution in treatment with dogwood and Highlander grass. 66

Figure 4.5. Correlation between the total salt concentration and the amount of CT water used in treatment with dogwood and highlander grass. 67

Figure 5.1. Water potential of dogwood and highlander grass during the first drought period. 88

Figure 5.2. Osmotic potential of dogwood and highlander grass during the first drought period. 89

Figure 5.3. Water potential of dogwood and highlander grass during and after the long drought period. 90

Figure 5.4. Osmotic potential of dogwood and highlander grass during and after the long drought period. 91

Figure 6.1. Rate of photosynthesis of dogwood and highlander grass under the first drought period. 114

Figure 6.2. Rate of photosynthesis of dogwood and highlander grass under the second longer drought period. 115

Figure 6.3. Cumulative leaf area of dogwood and highlander grass. 116

Figure 6.4. Cumulative shoot dry weight of dogwood and highlander grass. 117

Figure 6.5. Shoot dry weight partitioning of dogwood. 118

Figure 6.6. Correlation between the shoot dry weight of dogwood and highlander grass and the accumulated salt concentration in the soil/sand column. 119

Figure 6.7. Total root dry weight of dogwood and highlander grass. 120

Figure 6.8. Total root length of dogwood and highlander grass in the surface soil of the soil/sand column. 121

Figure 6.9. Root volume of dogwood and highlander grass. 122

Figure 6.10. Root length distribution of dogwood and highlander grass in the treatment with CT water level at 0 cm depth. 123

Figure 6.11. Root length distribution of dogwood and highlander grass in the treatment with CT water level at 30 cm depth. 124

Figure 6.12. Root length distribution of dogwood and highlander grass in the treatment with CT water level at 60 cm depth. 125

List of Symbols

EC	Electrical conductivity
θ_m	Gravimetric water content
θ_v	Gravimetric water content
ρb	Bulk density
Mo	Moist dry weight of the sample
Md	Oven dry weight of the sample
EC_{pw}	Electrical conductivity of the soil pore water
EC_{sp}	Electrical conductivity by the saturated paste
W_{sp}	Gravimetric water content of the saturated paste
Ψ_w	Water potential
Ψ_s	Osmotic potential
Ψ_p	Turgor potential
C	Solute concentration
R	Gas constant
T	Temperature in kelvin

Chapter - 1

Introduction

1.1. Background

Canada has the world's largest known oil reserves in its oil sand deposits (Syncrude, 1999). Alberta, the main oil-producing province, has a reserve of 1.7 trillion barrels of oil, accounting for a third of the world's known reserves (Bennett, 1996). There are four oil sand deposits in Alberta (Athabasca, Cold Lake, Wabasca and Peace River), of which the Athabasca deposit is the largest with an estimated in-place reserve of 869 billion barrels of bitumen (FTFC, 1995). There are currently two major oil sand production facilities in the Athabasca region; one operated by Syncrude Canada Ltd. and the other by Suncor Inc. Both are located north of Fort McMurray near the Athabasca river at approximately 57° 00' N, 111°35'W (Figure1.1).

These two oil-sand surface mining operations in northern Alberta produce about 333,800 barrels of synthetic crude oil per day (FTFC, 1995). Approximately 100 barrels of water is used to produce one barrel of synthetic oil, which, results in the production of about 132 barrels of oil sand tailings per year with a solid content of 45% to 50% by mass (Dawson, 1994). The two companies produce about 122 million barrels of synthetic crude oil, requiring 12 billion barrels of water and resulting in 16 billion barrels of tailings each year (FTFC, 1995). About 15 million m^3 of fine tailings are accumulated every year by Syncrude alone (List and Lord, 1996). These quantities are demonstrative of the tremendous scale of the oil sand mining operations. Although procedures for the handling and disposal of tailings are simple, the volumes to be dealt with impose practical constraints on reclamation planning (Moneco, 1983).

1.2. Oil recovery process

In the oil extraction process (hot water extraction process), oil sands are mixed with hot water and sodium hydroxide (NaOH), where the caustic NaOH helps in separating bitumen from the oil sand (FTFC, 1995). However it makes the tailings more saline. The oil extraction process produces huge volumes of wastes consisting of water, sand, silt, clay and residual bitumen, known as oil sand tailings. After bitumen is extracted, tailings are allowed to settle in a settling pond. Sand particles settle quickly leaving behind suspended silt and clay particles (fine tailings) (Figure 1.2).

1.3. Tailings sand

Tailings sand deposits consist of about 95% sand, 4% silt and 1% clay (H.B.T.T., 1989). These sands are slightly alkaline because NaOH was added during the extraction process, and the oil sand also contains salt (Lesko, 1974). Organic matter content is as low as <1% and available nitrogen and phosphorus are also low (Table 1.1). Other physical and chemical properties have been found to be suitable for plant growth (Moneco, 1983). Moneco (1983) and Techman (1983) have reported techniques to reclaim and revegetate tailings sand.

1.4. Fine tailings and mature fine tailings (MFT)

Fine tailings account for 5% to10% of the tailings by weight. The fine particles can remain suspended in water for prolonged periods. Syncrude's fine tailings are about 85% water, 13% silt and clays and 2% bitumen by weight (FTFC, 1995). Fresh fine tailings are considered to be acutely toxic for aquatic microorganisms due to the presence of a number of organic compounds, such as naphthenic acid, which is derived from bitumen. However, toxicity decreases with time due to degradation by microorganisms (Hunter et al., 1989).

The presence of sodium from the extraction process and residual bitumen prevent settling of fine tailings because sodium causes dispersion of clay particles. The dispersion of clay particles increases the volume of fine tailings considerably, which creates the storage problem for the fine tailings. De-watering under natural process is almost impossible and it may take centuries to attain the consistency of soft soils (Sheeran, 1993). Fine tailings, which have been stored in the settling pond for years and have essentially stopped settling, are called mature fine tailings (FTFC, 1995).

In order to understand the magnitude of the problem associated with managing mature fine tailings, it is important to construct a model of fine tailings production based on the operational numbers. When the Syncrude plant was opened in 1978, it was designed to produce 125,000 barrels of crude oil each day (Smith, 1979). To meet this requirement, 231,000 tons of bituminous ore were required each day (ALCRC, 1982), or 1.85 tons of oil sand per barrel of oil production. The space created by extraction of one ton of bituminous ore is 0.4 m^3 and the tailings, which are produced by processing that ore, occupy 0.6 m^3 (Simpson-Lewis et al., 1979). Syncrude's daily use of 231,000 tons of ore opened up 92,000 m^3 of space but produced tailings that required 138,600 m^3 of storage, a volumetric discrepancy of 46,000 m^3 per day of operation. Currently approximately 400 million m^3 of MFT at a solid content of ~ 30% are stored and if the current discharge method continues it has been estimated that by year 2018, the space required would be 800 million m^3 (Boratynec et al., 1998).

1.5. Management of mature fine tailings

Currently, fine tailings stored in the tailing pond pose a major environmental concern. It is important to either develop an environmentally acceptable disposal method, or reclaim the fine tailings, or a combination of the two. Several approaches have been attempted to accelerate the dewatering of fine tailings, such as spiking (Cuddy et al., 1993; Shaw et al., 1993; Lo et al., 1994), natural freeze and thaw (Sego et al., 1994), de-watering by plants (Silva et al., 1998), and the production of non-segregating tailings also known as composite tailings (CT) (Scott et al.,1993; Caughill et al., 1994).

In spiking, dense fine tailings from the settling basin are added to the coarse tailings slurry, and thereby increasing the fine solid contents of the fluid phase (Cuddy et al., 1993; Shaw et al., 1993; Lo et al., 1994). Long cold winter of Northern Alberta is a favorable condition for the de-watering of mature fine tailings by successive freeze-thaw. Thin layers of dense fine tailings are frozen in winter. In the freezing process, solids and water are separated as the ice crystals grow. The following spring and summer, upon thawing, the consolidated fine solids settle under gravity to the bottom while clean water accumulates at the surface (Sego et al., 1994). In a study conducted at the University of Alberta, plants have been used to take up the water from the mature fine tailings and hence increased the solid content (Silva et al., 1998).

1.6. Composite tailings (CT)

One of the techniques used by Syncrude Canada Ltd. to reduce the volume of fine tailings is the production of composite tailings (CT). In the production of composite tailings, mature fine tailings (30%), tailings sand (70%), and gypsum (800 – 1200 g/m^3 of tailings) are mixed (Sego et al., 1993) to produce non-segregating mixture known as CT. Calcium from gypsum ($CaSO_4$) replaces sodium from the fine tailings and causes clay particles to flocculate. The flocculation of clay particles facilitates stronger clay matrix in the tailings mixture, which causes sand particles to act as an internal surcharge by increasing the pressure that aids in compressing the clay structure of the tailings (Tan, 1995). Due to the increase in the density and removal of sodium, CT settles faster by self-weight consolidation. The consolidation of CT decreases the porosity from 85% to 55%, and increases the solid contents from 32% to 82% by releasing the entrapped water (FTFC, 1995). Composite tailings become trafficable within a year or two, making reclamation possible. Water released after the self-weight consolidation of CT is known as CT water, which is high in sodium and salt making reclamation of CT for vegetation problematic. The chemical properties of fine tailings and CT are given in Table 1.1.

Analysis of CT water has shown that it contains primarily sodium (1100 mg/l), sulfate (1500 mg/l) and chloride (550 mg/l). The electrical conductivity was recorded in the range of 4.6 – 5.0 dS/m and the pH was measured at 8.5. A boron concentration of 3.5 mg/l has also been reported (Renault et al., 1999). These properties of CT water make it unsuitable for plant growth. Studies have shown that high salt concentration in the soil solution can cause water, ionic and nutritional stress (Greenway and Munns, 1980).

Presence of dissolved salt in the soil solution creates physiological drought conditions, which reduce osmotic potential of soil water, and therefore, reduce plant water uptake. The reduction in plant water uptake causes water stress condition for plants and therefore reduces growth and survival. Increase in the concentration of specific ions such as chloride, sodium, boron and potassium also has characteristic effect on plant metabolism, which ultimately causes the nutritional stress in plants (Greenway and Munns, 1980).

1.7. Rationale of the study

Many of the studies done on fine tailings, like spiking (Cuddy et al., 1993; Shaw et al., 1993; Lo et al., 1994), production of CT, dewatering by freezing and thawing (Sego et al, 1994) are focused on increasing the solid content and hence reducing the volume of mature fine tailings. Other reclamation research on CT has focused on determining the salt tolerance levels among native boreal plant species (Silva et al., 1998; Renault et al., 1998, 1999; Croser and Zwiazek, 2000). One possible reclamation technology for re-vegetation on composite tailings might be the capping of CT with the tailings sand and then with the reclamation material (MacKinnon et al., 2000) (Figure 1.4 a). This capping technology would help to prevent salt movement from the released CT water to the rooting zone. The sand cap would reduce the upward migration of salt released from the CT and enhance survival of plants. Any accumulated salt from the CT water could then be removed by leaching and/or by drainage.

The saline nature of the CT water makes it necessary to prevent the accumulation of salt from the CT water in the root zone in order to ensure success of reclamation operations. This study focuses the capping technology (Figure 1.4). The purpose of this research was to monitor the effects of saline CT water released by the self-weight consolidation of CT, on plant growth, and to determine if capping by tailings sand can effectively prevent upward movement of salt to the rooting zone. In the capping design, tailings sand cap was used as a "capillary barrier" so that excessive accumulation of salt in the rooting zone could be minimized and the long-term sustainability of the ecosystem developed on the reclaimed CT could be ensured. The

the surface soil to develop salt free rooting zone? If CT water rises to the surface soil/sand interface, the intended function of the tailings sand as a capillary barrier between saline CT water and the surface soil is lost. On the other hand, too much sand between CT and surface soil may make the cost of the reclamation operations too high.

Salt movement in soil depends on the water content of soil, infiltration/soil water balance, hydrological properties of soil, and the rooting and water use pattern of plants. Water content of soil depends on the rate of water supply either in the form of rain or irrigation water, water holding capacity of soil, evaporation rate and also on the rate of water uptake by the plants roots. In reclaiming saline soils, contact of roots with the salt can't be prevented, therefore selection of plant species is important. Dogwood (*Cronus stolonifera* Michx.) has been found to be a relatively salt tolerant species among boreal plants and it is also a native species to the boreal region (Renault et al., 1998, 1999). Highlander grass is also a native species. No work has been done (which I am aware of) on the salt tolerance of highlander grass (*Elymus trachycaulus* subsp. *Trachycaulus*). These two plant species were selected as the test plant species.

1.8. Objective

The CT water is chemically complex and its behavior may differ from the pure salt solutions. My hypothesis is that the fundamental physical principle governing transport of salts in soil is also applicable to salts in CT water. The fundamental physical principle governing salt and water migration in soil and the effects of the physical properties of the soil, the sand and climate are largely known. What needs to be determined is how the interaction of CT water level in the soil profile affects the water uptake and plant growth, and also how these interactions affect the dynamics of salt movement and its distribution in the soil profile. The main objectives of my study are:

(i) To provide information on salt movement from the CT water to the tailings sand cap and to the soil.

(ii) To determine the impact of CT water on the growth of the two test plant species.

(iii) To determine the minimum thickness of the sand cap or in other words, to determine the most suitable depth of CT water level in the soil/sand profile, to prevent excessive accumulation of salt in the soil layer so that vegetation can be established.

1.9. Thesis outline

Review of previous work on salt movement and salt accumulation in soil, leaching requirement, and effects of salt on plant water uptake and plant growth is presented in chapter two. Chapter 3 gives detailed descriptions of the experimental procedures. In chapter 4, the findings of salt movement and salt distribution in the soil profile are presented. Chapter 5 presents my findings of the effect of saline CT water on plant water relations including leaf water potential, and osmotic potential. Chapter 6 discusses the impact of CT water on the above ground (shoot) and below ground (root) biomass of the two plant species. It also contains the analysis of root length distribution in the soil profile. Chapter 7 contains the synthesis of my study and the recommendations based on my findings, for implementing the reclamation planning for the composite tailings in the field.

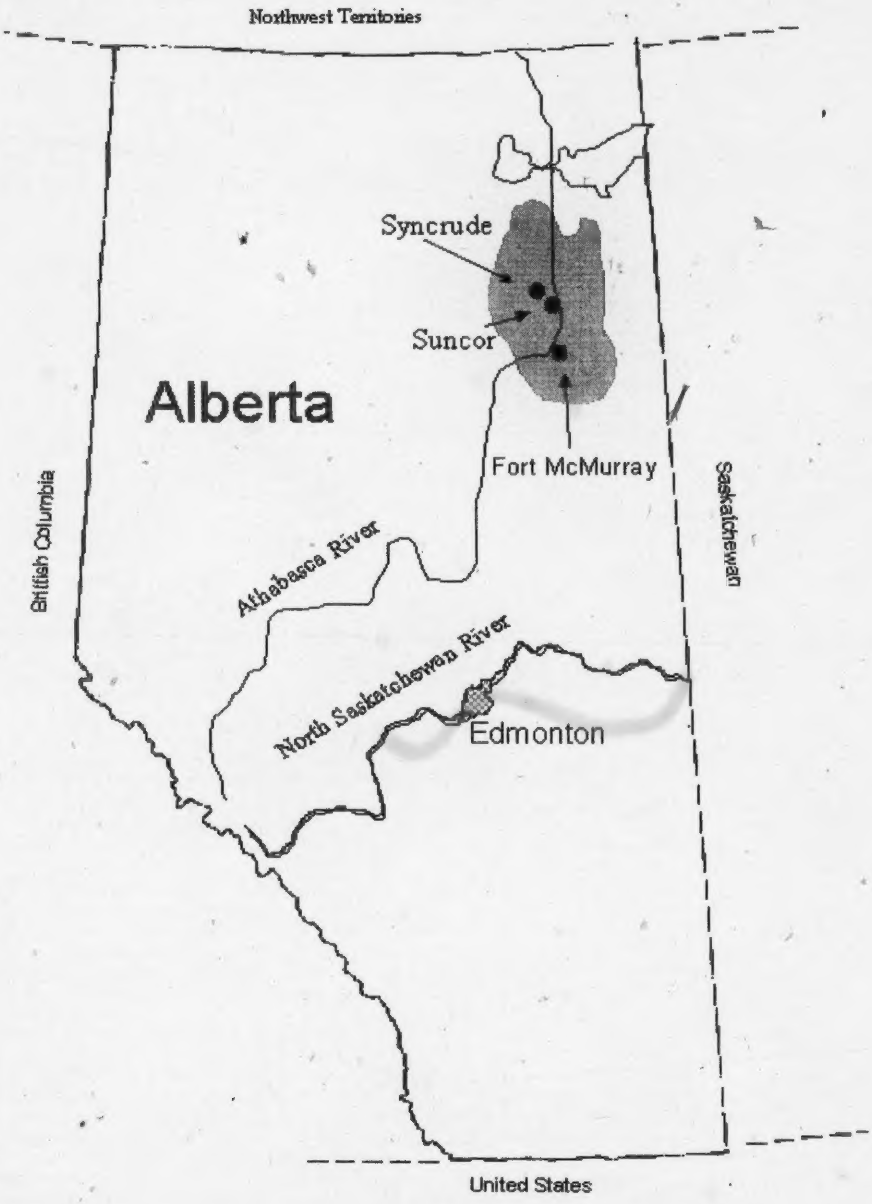
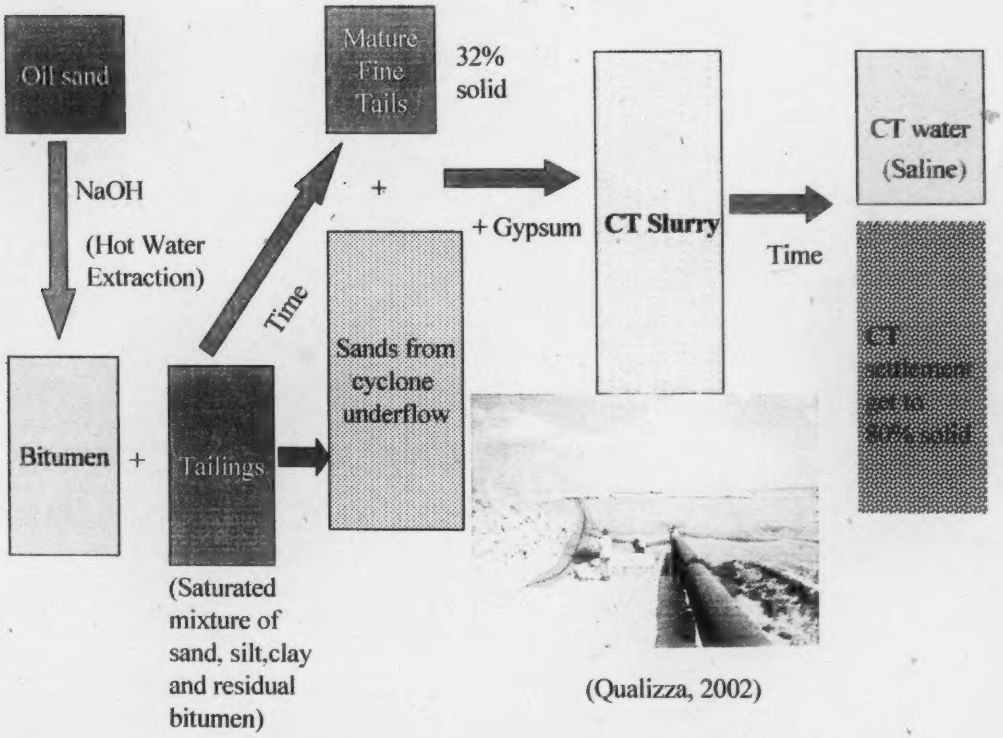

Northwest Territories
Syncrude
Suncor
Alberta
Fort McMurray
British Columbia
Saskatchewan
Athabasca River
North Saskatchewan River
Edmonton
United States

Fig 1.1 Mine sites where Syncrude Canada Ltd. is located (adapted from Stewart, 1963).


Oil sand
NaOH
(Hot Water Extraction)
Bitumen
+
Tailings
(Saturated mixture of sand, silt,clay and residual bitumen)
Time
Mature Fine Tails
32% solid
+
Sands from cyclone underflow
+ Gypsum
CT Slurry
Time
CT water (Saline)
CT settlement get to 80% solid

(Qualizza, 2002)

Figure 1.2. Schematic diagram of the oil recovery process, and the production of composite tailings (CT), Photograph in the box shows the storage area of CT where CT is transferred to the storage area through the pipe. (Photo courtesy of Qualizza, 2002).

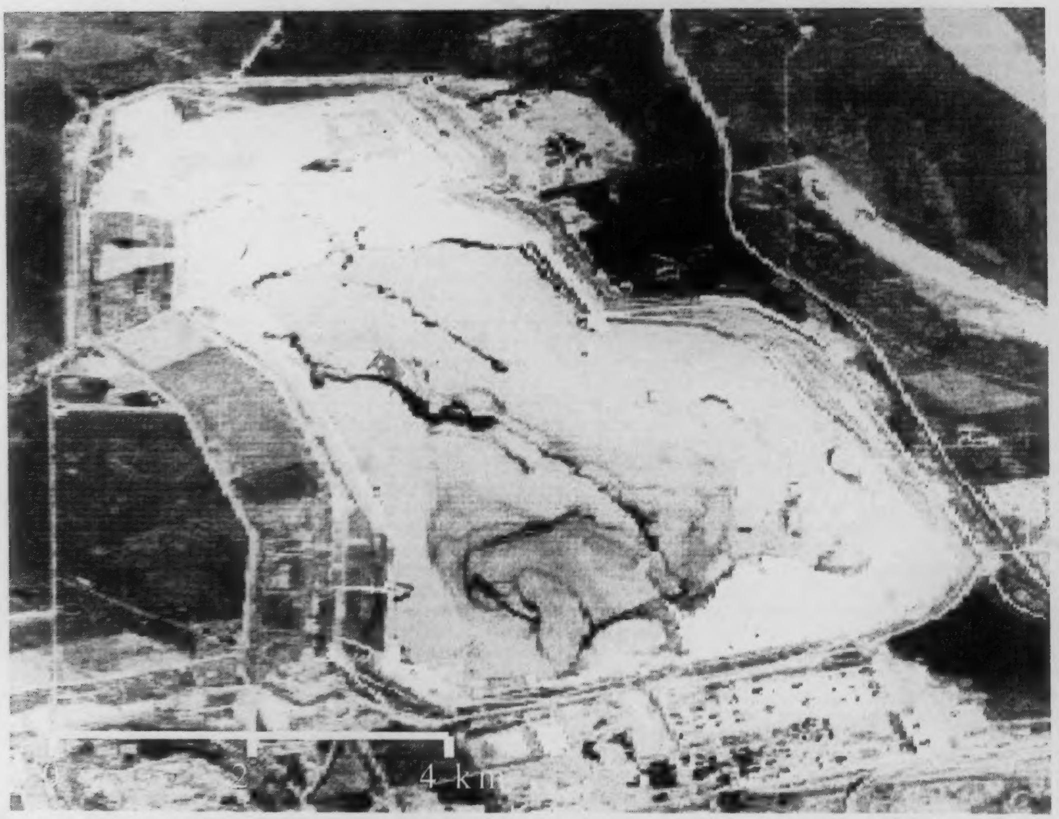
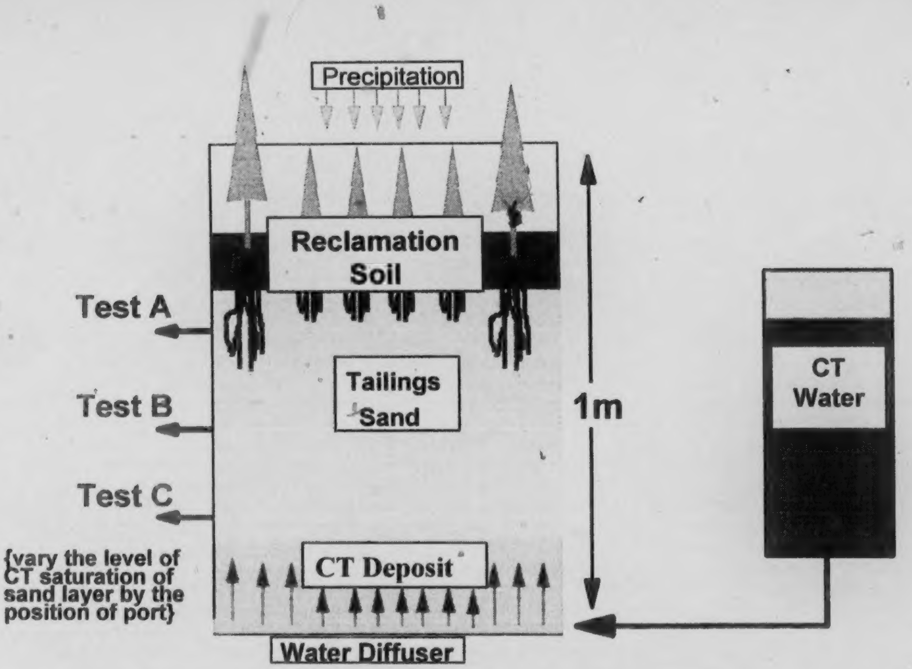
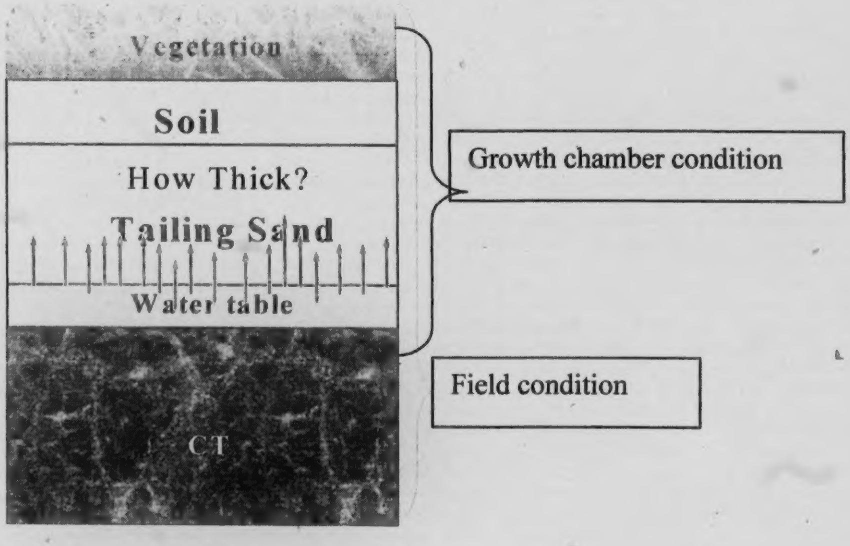


Figure 1.3. Aerial view of the Mildred lake settling pond at Syncrude in Fort Mc Murray, which is used to store fine tailings (Syncrude, 1999).


Precipitation
Reclamation Soil
Test A
Test B
Test C
{vary the level of CT saturation of sand layer by the position of port}
Tailings Sand
1m
CT Water
CT Deposit
Water Diffuser

(a) Capping technology proposed by MacKinnon (2000).


Vegetation
Soil
How Thick?
Tailing Sand
Water table
CT
Growth chamber condition
Field condition

(b) Growth chamber set up

Figure 1.4. Schematic diagram of the proposed reclamation technology

Table 1.1 Properties of tailings sand and composite tailings

	Tailings sand*	Composite tailings**
Sand	95%	85%
Silt	4%	10%
Clay	1%	5%
PH	8.2	7 – 8.5
EC	0.6 dS/m	2 – 6 dS/m
Nitrogen	< 0.5 mg/L	< 0.01 mg/L
Phosphorus	3.5 mg/L	< 0.01 mg/L
Potassium	40 mg/ L	10 mg/L

* H.B.B.T., 1989

** Renault and Zwaizek, 1997

1.10. References

ALCRC, 1982. Reclamation Research Annual Report, 1982. Alberta Land Conservation and Reclamation Council. Reclamation Research Technical Advisory Committee Report. RRTAC No. 82-3, Edmonton, Alberta, Canada.

Bennet, S., 1996. Sands facts. Oil sands information card produced for the Oil Sands Discovery Centre, Fort McMurray, Alberta, Canada.

Boratynec, D. J., R. J. Chalaturnyk, and J. D. Scott, 1998. Experimental and fundamental factors affecting the water release rates of CT. Unpublished paper. Dept. of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, Canada.

Caughill, D. L., J. D. Scott, Y. Liu, R. Burns, and W. H. Shaw, 1994. 1993 Field program on non-segregating tailings at Suncor Inc. Proceedings of 47th Canadian Geotechnical Conference, September, 1994. Halifax, Canada.

Croser, C., and J. J. Zwiazek, 2000. The effects of alum and gypsum consolidated tailings on the survival, growth, and mineral composition of dogwood (*Cornus stolonifera*) and raspberry (*Rubus idaeus*). Dept. of Ren. Res. University of Alberta, Edmonton. Report compiled for Syncrude Canada Ltd.

Cuddy, G., R. L. Lahale, and D.W. Mimura, 1993. Spiking tailings as a method to increase fines retention in beach deposits. Proceedings of Fine Tailings Symposium, Oil Sands - Our Petroleum Future Conference, April, 1993, Edmonton, Alberta, Canada. Paper F21: 1-21.

Dawson, R. F., 1994. Mine Waste Geotechnics. Ph.D. thesis. Department of Civil Engineering, University of Alberta, Edmonton, Canada.

FTFC (Fine Tailings Fundamental Consortium), 1995. Advances in Oil Sands Tailings Research, Alberta Department of Energy, Oil Sands and Research Division, Edmonton, Alberta, Canada.

Greenway, H., and R. Munns, 1980. Mechanisms of salt tolerance in nonhalophytes. Ann. Rev. Plant. Physiol. 31: 149-190.

H. B. B.T. Limited, 1989. Manual of plant species suitability for reclamation in Alberta. 2nd ed. Rep. no. RRTAC89-4 Alberta Land Conservation and Reclamation Council, Edmonton, Alberta, Canada.

Hunter, H. W., M. Mackinnon, and J. Ratallack, 1989. Sludge capping for the disposal of oil sands sludge. Proceedings of the 5th Annual Applied Aquatic Studies Workshop, Feb 21-22, 1989. University of Alberta, Edmonton, Canada.

Lesko, G. L., 1974. Preliminary revegetation trials on tar sands tailings at Fort McMurray, Alberta. Northern Forest Research Centre Info Rep. NOR-X-103, Edmonton, Alberta, Canada.

List, B. R., and E. R. F. Lord, 1996. Tailings management practices at Syncrude - from research to practice. Tailings and mine waste. 4: 631 - 641.

Lo, R. C., E. R. F. Lord, and J. M. Coward, 1994. Oil sand tailings reclamation involving sand-fines mixtures, Proceedings of the First International Congress on Environmental Geotechnics, July 1994, Edmonton, Alberta, Canada. 519-524.

MacKinnon, M. D., J. G. Matthews, W. H. Shaw, and R. G. Cuddy, 2000. Water quality issues associated with implementation of composite tailings (CT) technology for managing oil sands tailings. Proceedings of Sixth International Conference on Environmental Issues and Management of Waste in Energy and Mineral Production (SWEMP 2000) Calgary, Alberta, Canada. 443-453.

Moneco Consultants Ltd., 1983. Soil reconstruction design for the reclamation of oilsand tailings. SESG-RRTAC #83-1.

Qualizza, C., 2002. Personal communication. Soil Scientist, Syncrude Environmental Centre, Mildred Lake, Fort McMurray, Alberta.

Renault, S., C. Lait, J. J. Zwiazek, and M. MacKinnon, 1998. Effect of high salinity tailings water produced from gypsum treatment of oil sands tailings on plants of the boreal forests. Environ. Pollution. 102: 177-184.

Renault, S., E. Paton, G. Nilsson, J.J. Zwiazek, and M.D. MacKinnon, 1999. Responses of boreal plants to high salinity oil sands tailings water. J. Environ. Qual. 28: 1957-1962.

Renault, S., and J. J. Zwiazek, 1997. Effects of CT materials on plants. Research Project Report. Dept. of Renewable Resources, University of Alberta, Edmonton, Canada. Prepared for Suncor Energy Inc. and Syncrude Canada Ltd.

Scott, D., Y. Liu, and D. L. Caughill, 1993. Fine tailings disposal utilizing non segregating mixes, Proceedings of Fine Tailings Symposium. Oil Sands - Our Petroleum Future Conference, April, 1993. Edmonton, Alberta, Canada. F18: 1-19.

Sego, D. C., R. F. Dawson, T. Dereniwski, and R. Burns, 1994. Freeze-thaw dewatering to reclaim oil sands fine tailings to a dry landscape, Proceedings of the 7th International Cold Regions Specialty Conference, March 1994. Edmonton, Alberta, Canada.

Sego, D. C., S. A. Proskin, and R. Burns, 1993. Enhancement of solid content of oil sands fine tails by chemical treatment and freeze thaw. Proceedings of the 46th Canadian Geotechnical Conference, April 4-7, 1993. Saskatoon, Canada. 392-400.

Shaw, W., B. Livingstone, and J. Beck, 1993. Disposal of fine tailings utilizing hydrocyclone techniques, Proceedings of Fine Tailings Symposium. Oil sands - Our Petroleum Future Conference, April 1993, Edmonton, Canada. F19: 1-20.

Sheeran, D. E., 1993. An improved understanding of fine tails structure and behavior. *In Fine Tails Fundamentals Consortium*.Proceedings of Oil Sands - Our Petroleum Future Conference. April 4-7, 1993. Edmonton, Alberta, Canada.

Silva, M. J., M.. A. Naeth, K. W. Biggar, D. S. Chanasyk, and D. C. Sego, 1998. Plant selection for dewatering and reclamation of tailings. Proceedings of Annual Meeting of the American Society for Surface Mining and Reclamation. 107-117.

Simpson-Lewis, W., 1979. Canada's special resources lands: A national perspective of selected land uses. Map folio No. 4. Lands Directorate, Environment Canada, Ottawa.

Smith, S., 1979. Alberta Oil Sands Environment Research Program Interim Report covering the period April 1975 to November 1978. Prepared by A.S. Mann, R.A. Hersey, R.T. Seider, and B. Kasinka-Banas. Edmonton, Alberta.

Stewart, G., 1963. Geological controls on the distribution of Athabasca Oil Sand reserves. *In*: Carrigy, M. (ed.). The K.A. Clark volume: a collection of papers on the Athabasca Oil Sands presented to K. A. Clark on the 75th anniversary of his birthday. Research Council of Alberta, Edmonton. 15-26.

Syncrude, 1999. http://www.syncrude.com/research/04_04.html

Techman., 1983. Woody plant establishment and management program for oil sands mine reclamation. Repot prepared for the Reclamation Research Technical Advisory Committee and The Oil Sands Environmental Study Group. Techman Engineers Ltd. Edmonton, Canada. Report # OSEG-RRTAC 83-5.

Chapter - 2

Literature Review

2.1. Introduction

Saline soils occur naturally, but increasing salinization of irrigated soils occurs when salts in irrigation water are concentrated in the surface soil by evapotranspiration. Approximately 50% of irrigated area of the world is either salinized or might get salinized in future (Tyagi, 1986). Soil salinity adversely affects plant physiological processes including transpiration, photosynthesis and growth by decreasing the soil water potential. The decrease in soil water potential reduces the water uptake and therefore decreases the plant water potential. Leaching of salt by frequent rainfall or irrigation water is the main practice used to control soil salinity.

This chapter discusses the salinity problem in reclaiming CT, measurement of salinity, salt movement in soil, the adverse effects on plant growth caused by salinity, and the current management practice used in salinity control for the crop growth.

2.2. Composite tailings

The extraction of bitumen from the oil sand ore generates large volume of fine tailings (Chapter 1). The solid fraction of fine tailings is approximately 50% fine to medium silt and 50% clay, with the clay fraction predominantly kaolinite. Fine tailings contain 85% water by volume (List and Lord, 1996). Dewatering from the fine tailings under natural conditions is a very slow process and it may take centuries for the fine tailings to reach the consistency of soft clay (FTFC, 1995). At current production levels, about, 15 million m^3 of fine tailings are accumulated in the settling basin every year in Northern Alberta (List and Lord, 1996).

One of the techniques used by Syncrude Canada Ltd. to reduce the volume of fine tailings, is the production of composite tailings (CT). Composite tailings is produced when mature fine tailings (30%), tailings sand (70%), and gypsum (800 – 1200 gm/m^3 of tailings) are mixed together (Sego et al., 1993). Calcium from gypsum ($CaSO_4$) replaces sodium from the fine tailings and causes clay particles to flocculate. This process releases the entrapped water, which is known as CT water. CT water contains elevated levels of SO_4^{2-} (from gypsum), and Na^+ (from exchange of the clay particles) and Ca^{2+}. Earlier analysis of CT water has shown that it contains sodium (1100 mg/l), sulfate (1500 mg/l) and chloride (550 mg/l). The electrical conductivity has been recorded in the range of 4.6 – 5.0 dS/m and the pH was measured at 8.5. Boron concentration of 3.5 mg/l has also been reported (Renault et al., 1999). These properties of CT water make CT water unsuitable for plant growth and pose a challenge for the reclamation of composite tailings for vegetation.

2.3. Measurement of soil salinity

The standard method for measuring soil salinity is by measuring electrical conductivity (EC) of the saturation extract. The EC measurements are easily performed and readily interpreted, as they are proportional to the concentration of soluble salts in the soil solution. The saturation extract is employed because it is easily produced in the laboratory and can be used to estimate the salt content of the soil solution in the available moisture range. EC of soil solution greater than 4 dS/m at 25° C is an indictor of saline soil (Richards, 1954).

2.4. Movement of salt in soil

Movement of salt in soil is a function of the soil water content is by diffusion and mass flow. At high soil water content, salt may move up to the soil profile by capillary rise in the presence of shallow ground water table and at low water content by diffusion. As salts move upward with soil water and deposit at the evaporating surface, concentration near the surface becomes much higher and a concentration gradient is formed, which tends to move salt back down into the profile by diffusion (Todd and Kemper, 1972). Downward movement of salt is also brought about by leaching by irrigation water or rainfall. Plants also play a major role in bringing salt up to the surface, specially in the arid ecosystem where plants act as "biological pumps" by taking up salts from subsoil layers and redepositing them on the soil surface (Roberts, 1950; Fireman and Heyward, 1952; Rickard and Koeugh, 1968; Jessup, 1969; Sharma and Tongway, 1973; Kline and McKell, 1974; Charley and West, 1975; Tieldemann and Klemmedson, 1973).

Factors affecting salt movement in soils are physio-chemical properties of soil, water management practices, topography, quality of water applied, depth of water table, shallow ground water quality and climatic conditions (Jamison, 1995). Soil properties that determine the behavior of soil water flow and salt movement include the hydraulic conductivity and soil water retention characteristics (WRC). Hydraulic conductivity of a soil is a measure of its ability to conduct water, whereas, water retention characteristic is an expression of its ability to store water.

Salt accumulation in the surface or in the rooting zone is mainly due to faster rate of upward movement of salt than the downward movement of salt. The difference in the upward and downward movement of salt creates the problem of soil salinization, especially in the arid and semi arid regions where annual precipitation is less (downward movement) than the actual transpiration (upward movement) due to the presence of shallow ground water table. Upward movement of saline water from a shallow water table increases salt accumulation in the rooting zone.

Salinity of soil water depends not only on the quantity of salt present but also on the water holding capacity of soil and therefore, the soil texture. At a given salt content on a dry-soil basis, the coarse-textured soil may have a soil solution concentration five times that of the fine-textured soil because of the low water holding capacity of the course textured soil. Other factors that affect salt movement include initial concentration of salt in the soil solution, pattern of water uptake by plant roots, the rate of movement of soil solution and the extent of leaching (McNeal et al., 1968). Leaching of the accumulated salt is the only current management practice routinely used to control soil salinity for crop production (Slation et al., 1994).

2.5. Leaching of excess salt

Leaching is defined as a process of dissolving and transporting soluble salts by the downward movement of water through the soil (Agricultural Canada, 1976). For successful leaching, the water table should be deep or lateral groundwater drainage should be sufficiently rapid. Otherwise, excess irrigation (required to leach the salt) can cause the progressive rise of the water table. Once the water table comes within 1-2 m of the of the soil surface, groundwater tends to seep upward into the root zone by capillary action and thus mixes the soil with salt between irrigations (Hillel, 1998). Too much water application is not only wastage of water, it also tends to remove essential nutrients from the soil, and impede aeration by waterlogging the soil. Therefore, optimal quantity of irrigation water must be applied to cause leaching.

2.5.1. Leaching requirement

Leaching requirement (LR) is the term coined for agricultural practices, which was developed by the U.S. Salinity Laboratory (Richards, 1954). Leaching requirement is the proportion of irrigation water that must pass through the root zone in order to control salinity at any specified level (FAO/UNESCO, 1973). Leaching requirement depends on the amount and frequency of irrigation/rainfall, salt concentration of the irrigation water, evapotranspiration, rooting depth, soil texture, and salt tolerance of the crop, which determines the maximum allowable concentration of the soil solution in the root zone.

The maximum concentration of salt in the soil solution in terms of electrical conductivity should be kept below 4 dS/m for sensitive crops (U.S. Salinity Laboratory, 1954). Salt tolerant crops such as beets, alfalfa, and cotton can tolerate the EC of 8 dS/m, whereas, very tolerant crops like barley may give good yield at salinity values as high as 12 dS/m (Hillel, 1998). Leaching requirement of a crop plant also depends on the hydraulic conductivity of the subsoil at the lower interface of the root zone. The flow rate through this zone may limit the attainable leaching fraction (Rhoades, 1974).

It is possible to maintain the soil solution in the rooting zone at a concentration essentially equal to that of the irrigation water by frequent application of irrigation water (Rawlins and Raats, 1975). In addition, the effects of matric and osmotic potentials on crop growth are additive (Wadleigh and Ayers, 1954), thus it is doubly important to maintain a higher soil moisture by frequent and sufficient irrigation in saline soil. However, leaching depends on the quality of irrigation water. Based on the miscible displacement theory it has been suggested that leaching soils at water content below saturation (e.g., under low-intensity sprinkling irrigation or rainfall, or under intermittent irrigation) could produce more efficient leaching and thereby reduce drainage problems in areas of high water tables (Nielsen and Bigger, 1961).

Leaching of salt in the natural environment, where the only source of water is precipitation, depends on the frequency and amount of rainfall, temperature, soil hydraulic conductivity and the plant species. Temperature controls the process of evaporation and transpiration, which is one of the major drivers of salt migration and their accumulation at the soil surface. Under natural condition, water table depth plays an important role in the upward migration of salt and eventually their accumulation in the rooting zone.

2.6. Salinity and soil-plant water relations

Plant water relations are affected by soil salinity (Bolanos and Longstrength, 1984). High level of salinity lowers the soil water potential due to development of osmotic potential, and hence reduces the plant water uptake (Greenway and Munns, 1980). The lowering of soil water potential creates physiological drought condition, in which water may be available in soil but plants cannot absorb it, which creates water stress condition for the plants (Katerji et al., 1996). Reduced water uptake causes plants to close their stomata to maintain the turgidity of leaves, which reduces the survival and productivity (Greenway and Munns, 1980). The extent of the osmotic effect depends on the type of the salt present in soil solution. Eaton (1942) demonstrated that choride salinity was twice as inhibitory as sulfate salinity per milliequivalent of salts in his sand-culture solution. Plants maintain the turgor potential and therefore, growth by lowering the osmotic potential of the cell sap (osmotic adjustment).

2.6.1. Osmotic adjustment

The water relations of plants are controlled primarily by cell water status (Kozlowski and Pallardy, 1997). Higher salinity reduces the soil's osmotic potential, which, reduces plant water uptake, and thereby reduces plant water potential. Plants reduce the osmotic potential of the cells to maintain turgor potential. Turgor potential is maintained primarily by increasing the solute concentration in the cell. Turgor potential is responsible for maintaining plant growth (Kramer, 1983). This adjustment in osmotic potential of plants cell in response to the reduced water potential is known as osmotic adjustment (Nobel, 1996). When plants are exposed to salt, like sodium chloride, ions reduce the apoplastic water potential and accumulate excessively in the cytosol (Binzel et al., 1988). Plant cells adjust osmotically to the water imbalance through synthesizing compatible organic solutes and accumulating ions from the external environment. Osmotic adjustment is also brought about by the change in the mineral composition in the leaves. Potassium change can account for much of the osmotic fluctuation (Bernstein, 1963). At higher salinity, osmotic potential of leaves decreases due to decrease in the osmotic potential of the soil solution, level of potassium in the leaf increases (Bernstein, 1963). The increase in potassium level may be due to increasing level of organic acids in the tissues, induced by higher salinity.

2.7. Specific ion toxicity

Presence of specific ions, as for example, SO_4^{2-}, Na^+, Cl^-, and Ca^{2+} in soil solution causes injury to the plants growing in saline soil. Increasing concentration of salt ions could result in growth reduction, if root-to-shoot transport rates of ions were maintained. Leaf necrosis is often due to ion toxicity. Necrosis has been related to foliar sodium and chloride content in eastern white pine (*Pinus strobus* L.) (Hall and Hofstra, 1972) and red pine (*Pinus resinosa* Aiton) (Sucoff et al., 1975).

Both sodium and chloride can be toxic at elevated levels in plant tissues. The sulfate ion may also be toxic in plant tissue (Chandler and Thorpe, 1987), but its effects are not well known. Woody plants are susceptible to injury by either Na^+ or Cl^- accumulation (Bernstein, 1975) and most woody plants tend to be more sensitive to excess chloride than to high levels of Na^+ (Shannon et al., 1994). A synergistic effect between Na^+ and Cl^- has also been reported, with greater injury occurring when both ions are present (Spotts et al., 1972; Martin and Koebner, 1995). A greater uptake of sodium has been reported under NaCl salinity than under Na_2SO_4 salinity at the same treatment concentration of Na^+ (Kahn et al., 1995; Renault et al., 2001). The mechanism behind the synergistic effect between Na^+ and Cl^- is not fully understood. *In vitro* studies have shown that high level of Na^+ and Cl^- inhibited protein synthesis and enzyme activity (Greenway and Munns, 1980). Evidence suggests that Na^+ and Cl^- ions may alter membranes, resulting in reduced selectivity. Sodium has been found to displace Ca^{2+} from the plasma membrane, and this is followed by K^+ efflux (Cramer et al., 1985). Chloride has been found to alter membrane lipid composition resulting in increased membrane permeability (Kuiper, 1968), and this leakage has been proposed as a mechanism of Cl^- induced injury (Bernstein, 1975).

2.8. Nutritional effects

Presence of salt in soil water increases the concentration of some ions specifically sodium and chloride (Epstein and Rains, 1987), which increases the ratio of these ions to other ions already present in the soil and cause deficiencies of nutrient elements present at much lower concentrations. Calcium plays important role in signal transduction and membrane integrity of plants. High levels of Na^+ may reduce the availability of Ca^{2+} in the substrate, however reported effects of salinity on tissue Ca^{2+} concentrations are variable. Reduced tissue Ca^{2+} content following NaCl treatment has been reported for roots and shots of sesame (*Sesamum indicum* L.) (Yahya, 1998), and leaves of sapodilla (Micklebart and Marler, 1996). Conversely, Ca^{2+} concentrations increased in roots and leaves of NaCl treated bean (Carbonell-Barraching et al., 1997), and increased with increasing treatment concentration of Na_2SO_4 in barley (*Hordeum vulgare* L.) (Janzen and Chang, 1987).

Potassium plays an important role in osmoregulation. Although plants are highly selective for K^+ uptake, reductions in tissue K^+ are frequently reported under high Na^+ conditions (Grattan and Grieve, 1994). Reduction in tissue K^+ has been observed in shoots of sesame (Yahya, 1998), oak (Alaoui-Sosse et al., 1998) and bean (Carbonell-Barraching et al., 1997). Saline conditions inhibit the absorption of potassium in mangrove (*Avicennia marina*) (Rains and Epstein, 1967). Aslam et al., (1984) found that sulfate and chloride diminished the rate of nitrate absorption. Reduction in N uptake may be due to competitive interactions between Cl^- and NO^-_3 ions.

2.9. Effect of salinity on photosynthesis

Photosynthesis is a major process determining growth, dry weight production and crop productivity. Salt in soil water reduces the water uptake by plant roots due to a decrease in the osmotic potential of the soil solution. Decrease in the soil osmotic potential prevents the water uptake by roots, which decreases the plants total water potential and hence the leaf conductance is reduced to prevent water loss. The photosynthetic capacity of many plant species has been shown to reduce by higher salinity (Downton, 1977; Seemann and Critchley, 1985; Walker et al., 1988; Awada et al., 1995; Mickelbart, and Marler, 1996). The reduction in photosynthesis is due to reduction in stomatal conductance and subsequent restriction of the availability of CO_2 for carboxylation (Brugnoli and Lauteri, 1999). Photosynthetic rates decreased in NaCl treated alfalfa species (Khavari-Nejad and Chaparzadeh, 1998), and several poplar (*Populus* spp.) (Fung et al., 1998), but were not inhibited by high levels of Cl^- or Na^+ in olive (*Olea europa* L.) (Tattini et al., 1995).

Reduced photosynthesis could also result from decreased content of photosynthetic pigments (Yeo and Flowers, 1986a). Reduction in the photosynthetic pigments in the leaves has often been observed under saline conditions. Cholorophyll-a content decreased in NaCl treated tomato (*Lycopercicon esculentum* Mill.) plants (Khavare-Nejad and Mostofi, 1998), and cholorophyll-a and cholorophyll-b decreased in alfalfa

(*Medicago sativa* L.) plants as concentration of NaCl treatment increased (Khavari-Nejad and Chapaarzadeh, 1998).

2.10. Salinity and growth

Salts in soil solution affect root growth in two ways. First, the decreased osmotic potential of the soil solution restricts water entry (Hayward and Spurr, 1944) and second, some of the ions present exert a specific toxic action on the activity of the plant cells (Hayward and Long, 1942; Waldeigh and Gauch, 1944). Long-term studies have found that growth declines more than photosynthesis (Papp et al 1983; Seemann and Critchely, 1985), suggesting that salinity affects carbon assimilation per plant via a smaller leaf area, rather than a reduced rate of photosynthesis (Munns, 1993). Salinity also inhibits plant growth by interfering with the uptake of essential nutrient ions (Huang and Redmann, 1995). The accumulation of sodium in plant tissues can affect enzyme activity, protein and nucleic acid synthesis, hormonal balance, membrane permeability, and can cause injury to tissues (Kuiper, 1984; Alam, 1994). High salinity reduces shoot dry weight and total leaf area (Brugnoli and Lauteri, 1999). Reduction in growth might be attributed to the reduction in leaf area, which reduces light interception (Marcelis and VanHooijdonk, 1999).

Rooting depth and leaf area index has a great effect on evapotranspiration, which is affected by available soil water in the root zone. Mayaki et al. (1976) observed significant reduction in leaf area index under water stress condition. However, Renault et al. (1998) observed decrease in the thickness of the leaves under water stress conditions. Root lengths of *Pinus* and *Picea* have been found to decrease with increasing salt concentration in the soil (Croser et al., 2001). The degree to which roots penetrate downward into higher salinity soils is a function of the salt tolerance level of the plant. Absorption of water by plant roots in the saline zone decreases with increasing salinity, and water absorption ceases completely when salinity reaches a critical level (Lunin and Gallatin, 1965).

Shoot dry weight is affected by salinity more severely than root dry weight, which causes reduction in shoot: root ratio (Meiri and Poljkoff-Mayber, 1969; Mass and Hoffman, 1977). However, Croser, (2001) reported a greater reduction in root length than shoot length, which could be a result of stage of root development. Roots may be more sensitive than shoots to salinity at younger stage. A greater root sensitivity to salinity has also been indicated for chickpeas (*Cicer arietinum*), and lentil (*Lens culinaris*) (Mamo et al., 1996). Mamo et al. (1996) also reported reduction in the number of lateral roots with increasing salinity.

2.11. Salt Tolerance

The growth and survival of plants in saline soils depend to a great extent on the degree to which plants can tolerate salinity in the soil. The mechanism by which salt tolerant species survive in saline condition is not fully understood. It has been found that in salt tolerant species, sodium level was increased whereas potassium level was decreased, whereas in salt sensitive species potassium level was increased during salinity stress (Greenway and Munns, 1980). In a study conducted by Renault (1999) to check the salt tolerance level of different tree species of the boreal mixed forest, dogwood was found to be more salt tolerant than other boreal plant species. Salt tolerant species have lower Na/K and Na/Ca ratios than the salt sensitive species (Renault et al., 1999). Khan et al. (1995) also reported that Na/K ratio was lower in salt tolerant cultivars than in susceptible ones. A high Na/K ratio decreases protein synthesis and enzyme activity (Botella et al, 1997) and a high Na/Ca ratio may cause an increase in membrane permeability and lower membrane integrity (Greenway and Munns, 1980).

In order to survive in saline conditions, some species are able to restrict the uptake of salt ions, or restrict their translocation to the shoot. Rootstocks of trifoliate (*Poncirus trifoliate* L. Raf.), and sweet orange (*Citrus sinensis* L.) differed in their leaf and stem Na^+ and Cl^-, but not in root Na^+ and Cl^- concentrations (Grieve and Walker, 1983) suggesting differences in their ability to restrict translocation. Other species that appear to retain Na^+ in the roots include oak (Alaoui-Sosse et al., 1998), sorghum

(Kahn et al., 1995), castor bean (Jescheke and Pate, 1991), and dogwood (*Cronus stolonifera* Michx.) (Renault et al., 2001).

Another potential mechanism by which plants could survive periods of high salinity would be to reduce transpiration rates, thereby theoretically reducing the translocation of ions to the shoot (Dalton et al., 2000). However, Franklin (2002) suggested that transpiration rates are not related to translocation rate of salt ions. Higher salt concentration in the substrate resulted in greater translocation to the shoot, although transpiration was similarly reduced in all treatment concentrations.

2.12. Summary

Accumulation of salt in the soil layer adversely affects plant growth. Salt accumulation in the soil profile is directly related to the amount and frequency of the irrigation water applied / rainfall. Salts in soil solution affect plant growth by three different ways, which include reduction in plant water potential, toxicity effect, and nutritional effect. Salt in soil decreases soil water potential, which restricts the water uptake by plant roots, and therefore, decreases the plant water potential, which ultimately creates water stress condition in plants. Plants maintain their growth in water stress by lowering their osmotic potential (osmotic adjustment). One of the possible mechanisms behind the osmotic adjustment is by increasing the solute concentration in the plant cell. Presence of specific ions such as SO_4^{2-}, Na^+, Cl^-, and Ca^{2+} causes injury to the plant growth. Presence of salt in soil solution increases the concentration of some specific ions as for example sodium as compared to the other ions, which are already present in the soil solution, which causes deficiency of nutrient elements present at much lower concentration. Salt in soil also decreases the rate of photosynthesis and growth of plants. However, the degree to which salt in soil affect plant growth depends to a great extent on the plant species. Therefore, selection of plant species becomes an important factor in the reclamation of saline soil for revegetation. Leaching of salt by irrigation water/rainfall is an important and primary factor in controlling soil salinity.

2.13. References

Agriculture Canada, 1976. Glossary of terms in soil science. Ottowa.

Alam, S. M., 1994. Nutrient uptake by plants under stress conditions. *In* , M . Pessarakli (ed.) *Handbook of Plant and Crop Stress*. Marcel Dekker Inc., New York. 227-246.

Alaousi-Sosse, B., L. Schmer, and P. Barnola, 1998. Effect of NaCl salinity on growth and mineral partitioning in *Quercus rober* l., a rhymically growing species. Trees 12: 424-430.

Aslam, M., R. C. Huffaker, and D. W. Rains, 1984. Early effects of salinity on nitrate assimilation in barley seedlings. Plant physiol. 76: 321-325.

Awada, S., W. F. Campbell, L. M. Dudley, J. J. Jurinak, and M. A. Khan, 1995. Interactive effects of sodium chloride, sodium sulfate, calcium sulfate, and calcium chloride on snapbean growth, photosynthesis, and ion uptake. J. Plant Nutri. 18: 889-900.

Bernstein, L., 1963. Osmotic adjustment of plants to saline media. II. Dynamic phase. Am. J. Bot., 50: 360-370.

Bernstein, L., 1975. Effects of salinity and sodicity on plant growth. Ann. Rev. Phytophathol. 13: 295-312.

Binzel, M., F. Hess, R. Brown, and P. Hassegawa, 1988. Intracellular compartmentalization of ions adapted tobacco cells. Plant Physiol. 86: 607-614.

Bolanos, J. A., and D. J. Longstreth, 1984. Salinity effects on water potential components and bulk elastic modules of *Alternanthera Philoxeroides* (Mart). Griseb. Plant Physiol. 75: 281-284

Botella, M. A., V. Martinez, J. Pardines, and A. Cerda, 1997. Salinity induced potassium deficiency in maize plants. J. Plant Physiol. 150: 200-205.

Brugnoli, E., and M. Lauteri, 1991. Effects of salinity on stomatal conductance, photosynthetic capacity, and carbon isotope discrimination of salt-tolerant (*Gossypium hirsutum* l.) and salt-sensitive (*Phaseolus vulgaris* l.) C_3 non-halophytes. Plant Physiol. 95: 628-634.

Carbonell-Barrachina, A. A., F. Burlo-Carbonell, and J. Mataix-Beneyto, 1997. Effect of sodium arsenite and sodium chloride on bean plant nutrition (macronutrients). J. Plant Nutr. 20: 1617-1633.

Chandler, S. F., and T. A. Thorpe, 1987. Characterization of growth, water relations, and proline accumulation in sodium sulfate tolerant callus of *Brassica napus* L. cv Westar (Canola). Plant Physiol. 84: 106-111.

Charley, J. L., and N. E. West, 1975. Plant-induced soil chemical patterns in some desert shrub-dominated ecosystems of Utah. J. Ecol. 63: 945-964.

Cramer, G. R., A. Lauchli, and V.S. Polito, 1985. Displacement of Ca^{2+} from the plasmalemma of root cells. A primary response to salt stress? Plant Physiol. 79: 207-211.

Croser, C., S. Renault, J. Franklin, and J. J. Zwaiazek, 2001. The effect of salinity on the emergence and seedling growth of *Picea mariana, Picea glauca*, and P*inus banksiana*. Environ. Pollution. 115: 9-16.

Dalton, F. N., A. Maggio, and G. Puccinni, 2000. Simulation of shoot chloride accumulation: separation of physical and biochemical processes governing plant salt tolerance. Plant and Soil. 219: 1-11.

Downton, W. J. S., 1977. Photosynthesis in salt-stressed grapevines. Aust. J. Plant Physiol. 4: 183-192.

Eaton, F. M., 1942. Toxicity and accumulation of chloride and sulfate salts in plants. J. Agric. Res. 64: 357-399.

Epstein, E., and D. W. Rains, 1987. Advances in salt tolerance. Plant and Soil. 99: 17-29.

FTFC (Fine Tailings Fundamentals Consortium), 1995. In Advances in Oil Sands Tailings Research, Alberta Department of Energy, Oil Sands and Research Division, Edmonton, Alberta, Canada.

Fireman, M., and H. E. Hayward, 1952. Indicator significance of some shrubs in Escalante Desert, Utah. Bot. Gaz. 114: 143-155.

Food and Agricultural organization of the United Nations (FAO/UNESCO). 1973. Irrigation, drainage and salinity. Hutchinson and co. Ltd., London.

Franklin, J. A., 2002. Effects of salt and CT water on jack pine. Ph.D. Thesis, Department of Renewable Resources, University of Alberta. Edmonton, Alberta. Canada.

Fung, L. E., S. S. Wang, A. Altman, and A. Hutterman, 1998. Effect of NaCl on growth, photosyntehses, ion and water relations of four poplar genotypes. For. Ecol. Mgmt. 107: 135-146.

Grattan, S. R., and C. M. Grieve, 1994. Mineral nutrient acquisition and response by plants grown in saline environments. *In*: M. Pessarakli (ed.) *Handbook of plant and crop stress*. Marcel Drekker Inc., New York. 203-226.

Greenway, H., and R. Munns, 1980. Mechanisms of salt tolerance in nonhalophytes. Ann. Rev. Plant. Physiol. 31: 149-190.

Grieve, A. M., and R. R. Walker, 1983. Uptake and distribution of chloride, sodium and potassium ions in salt treated citrus plants. Australian J. of Agric. Res. 34: 133-143.

Hall, R., and G. Hofstra, 1972. Effects of deicing salt on eastern white pine: foliar injury, growth suppression and seasonal changes in foliar concentrations of sodium and chloride. Can. J. For. Res. 2: 244-249.

Hayward, H. E., and W. B. Spurr, 1944. Effects of isosmotic concentrations of inorganic and organic substrates on entry of water into corn roots. Bot. Gaz. 106: 131-139.

Hayward, H. E., and E. M. Long, 1942. Vegetative responses of the Alberta peach on Lovell and Shalil rootstocks to high chloride and sulfate solutions. Am. Soc. Hort. Sci. Proc. 41: 149-155.

Hillel, D., 1998. Environmental Soil Physics. Academic Press. New York.

Huang, J., and R. E. Redmann, 1995. Salt tolerance of *Hordeum* and *Brassica* species during germination and early seedling growth. Can. J. Plant Sci. 75: 815-819.

Jamison, V. C., 1955. Pertinent factors governing the availability of soil moisture to plants. Soil Sci. 81: 459-471.

Janzen, H. H., and C. Chang, 1987. Cation nutrition of barley as influenced by soil solution composition in a saline soil. Can. J. Soil Sci. 67: 619-629.

Jeschke, W. D., and J. S. Pate, 1991. Cation and Chloride partitioning through xylem and phloem within the whole plant of *Ricinus communis* L. under conditions of salt stress. J. Exp. Bot. 42: 1105-1116.

Jessup, R. W., 1969. Soil salinity and saltbush country of northeastern south Australia. Trans. R. Soc. South Aust. 93: 69-78.

Katerji, N., J.W. van Hoorn, A. Hamdy, F. Karam, and M. Mastrorilli, 1996. Effect of salinity on water stress, growth, and yield of maize and sunflower. Agric.Water Manag. 30: 237-249.

Khan, A. H., M. Y. Ashraf, S. S. M. Naqvi, B. Khanzada, and M. Ali, 1995. Growth, ion and solute contents of sorghum grown under NaCl and Na_2SO_4 salinity stress. Act. Physiol. Plant. 17: 261-268.

Khavari-Nejad, R. A., and N. Chaprzadeh, 1998. The effects of NaCl and $CaCl_2$ on photosynthesis and growth of alfalfa plants. Photosynthetica 35: 461-466.

Khavari-Nejad, R. A., and Y. Mostofi, 1998. Effects of NaCl on photosynthetic pigments, saccharides, and choloroplast ultrastructure in leaves of tomato cultivars. Photosynthetica 35: 151-154.

Kline, L. G., and C. M. McKell, 1974. Role of annual grasses and shrubs in nutrient cycling of Great Basin plant communities. US/IBP Desert Biome Res. Memo RM74-14. Utah State University, Logan.

Kozlowski, T., and S. Pallardy, 1997. Physiology of Woody Plants. 2nd Edn. Academic Press, San Diego.

Kramer, P. J., 1983. Water relations of plants. Academic Press, New York.

Kuiper, P. J. C., 1968. Lipids in grape roots in relation to chloride transport. Plant physiol. 43: 1367-1371.

Kuiper, P. J. C., 1984. Functioning of plant cell membranes under saline condition. *In* R.C. Staples and G.H. Toenniessen (ed.) *Salinity tolerance in plants*. Wiley Interscience. New York.

List, B. R., and E. R. Lord, 1996. Tailings management practices at Syncrude- From research to practice. Proceedings, tailings and mine waste. Fort Collins, Colarado.

Lunin, J., and M. H. Gallatin, 1965. Salinity-fertility interaction in relation to the growth and composition of beans. Agron. J. 57: 339-345.

Mamo, T., C. Richter, and B. Heiligtag, 1996. Salinity effects on the growth and ion contents of chickpea (*Cicer arietinum* L.) and lentil (*Lens culinaris*. Medic.) varieties. J. of Agron. and Crop Sci. 176: 235-247.

Marcelis, L. F. M., and J. van Hooijdonk, 1999. Effect of salinity on growth, water use and nutrient use in radis (*Raphanus sativus* l.). Plant and Soil. 215: 57-64.

Mass, E. V. and G. J. Hoffmann, 1977. Crop salt tolerance- Current Assesment. J. Irri. Div. Proc. Am. Soc. Civ. Eng. 103 (IR2): 115 - 134.

Martin, P. K., and R. M. K. Koebner, 1995. Sodium and chloride ions contribute synergistically to salt toxicity in wheat. Biol. Plant. 37: 265-271.

McNeal, B. L., D. A. Layfield, W. A. Norvell, and J. D. Rhoades, 1968. Factors influencing hydraulic conductivity of soils in the presence of mixed-salt solutions. Soil Sci. Soc. Amer. Proc. 32: 187-193.

Meiri, A., and A. Poljakoff-Mayber, 1969. Effect of various salinity regimes on growth, leaf expansion and transpiration rate of bean plants. Soil Sci. 109: 26-34.

Mickelbart, M. V., and T. E. Marler, 1996. Root-zone sodium chloride influences photosynthesis, water relations, and mineral content of sapodilla foliage. Hort. Sci. 31: 230-233.

Munns, R., 1993. Physiological process limiting plant growth in saline soils. Some dogma and hypotheies. Plant Cell Environ. 16: 15-24.

Nielsen, D. R., and J. W. Bigger, 1961. Miscible displacement. I. Experimental Information. Soil Sci. Soc. Amer. Proc. 25: 1-5.

Nobel, P. S., 1996. Physiochemical and environmental plant physiology. Academic Press. San Diego.

Papp, J. C., M. C. Ball, and N. Terry, 1983. A comparative study of the effects of NaCl salinity on respiration, photosynthesis and leaf extension growth in *Beta vulgaris* (sugar beet). Plant, Cell and Environment, 6: 675-677.

Rain, D. W., and E. Epstein, 1967. Preferential absorption of potassium by leaf tissue of the mangrove, *Avicennia marina*: an aspect of halophytic competence in coping with salt. Aust. J. Bio. Sci. 20: 847-857.

Rawlins, S. L., and P. A. C. Raats, 1975. Prospects for high frequency irrigation. Science. 188: 604-610.

Rickard, W. H., and R. F. Keough, 1968. Soil-plant relationships of two stepped desert shrubs. Plant and Soil. 29: 205-213.

Renault, S., C. Croser, J. A. Franklin, and J. J. Zwiazek, 2001. Effects of NaCl and Na_2So_4 on red osier dogwood (*Cornus stolonifera* Michx) seedlings. Plant and Soil. 233: 261-268.

Renault, S., C. Lait, J. J. Zwiazek, and M. MacKinnon, 1998. Effect of high salinity tailings waters produced from gypsum treatment of oil sands tailings on plants of the boreal forests. Environ. Pollution. 102: 177-184.

Renault, S., E. Paton, G. Nilsson, J. J. Zwiazek, and M. D. MacKinnon, 1999. Responses of boreal plants to high salinity oil sands tailings water. J. Environ. Qual. 28: 1957-1962.

Rhoades, J. D., 1974. Drainage for salinity control. *In* J. van Schilfgaarde. (ed.) Monograph no.17, Am. Soc. Agron. Madison. WI.

Richards, L. A., 1954. Diagnosis and Improvement of Saline and Alkali Soils. Agriculture Handbook no. 60. United States Department of Agriculture, Washington, D.C.

Roberts, R. C., 1950. Chemical effects of salt tolerant shrubs on soils. Trans. Int. Congs. Soil Sci. 1: 404-406.

Sego, D. C., S. A. Proskin, and R. Burns, 1993. Enhancement of solid content of oil sands fine tails by chemical treatment and freeze thaw. Proceedings of the 46th Canadian Geotechnical Conference, April 4-7, 1993. Saskatoon, Saskachewan. Canada. 392-400.

Seeman, J. R., and C. Critchley, 1985. Effects of salt stress on the growth, ion content, stomatal behaviour and photosynthetic capacity of a salt sensitive species, *Phaseolus vulgaris* L. Planta. 164: 151-162.

Shannon, M. C., C. M. Grieve, and L. E. Francois, 1994. Whole-plant response to salinity. *In*: R.E. Wilkinson (ed.) *Plant Environment Interactions*. Marcel Dekker. New York. 199-244.

Sharma, A. P., and D. J. Tongway, 1973. Plant induced soil salinity patterns in two saltbush (*Atriplex* sp.) communities. J. Range Manage. 26: 27-29.

Slation, N. A., R. J. Norman, B. R. Wells, D. M. Miller, R. S. Helms, C. A. Beyrouty, and C. E. Welison, Jr, 1994. Efficient use of fertilizer. *In*: Rice production handbook. 42-54. University of Arkansas Coop. Ext. Service, Little Rock.

Spotts, R. A., J. Altman, and J. M. Staley, 1972. Soil salinity related to Ponderosa pine tip burn. Phytopathology. 62: 705-708.

Stark, J. M., and E. F. Redente, 1986. Trace element and salt movement in retorted oil shale disposal sites. J. Envrion. Qual. 15 : 282-288.

Sucoff, E., R. Feller, and D. Kanten, 1975. Deicing salt (sodium chloride) damage to *Pinus resinosa* Ait. Can. J. For. Res. 5: 546-556.

Tattini, M., R. Gucci, M. A. Cordaschi, C. Ponzio and J. D. Everad, 1995. Growth, gas exchange and ion content in *Olea europa* plants during salinity stress and subsequent relief. Physiol. Plant. 95: 203-210.

Teidmann, A. R., and J. O. Klemmedson, 1973. Effects of mesquite on physical and chemical properties of the soil. J. Range Manage. 26: 27-29.

Todd, R. M., and W. D. Kemper, 1972. Salt dispersion coefficients near an evaporating surface. Soil Sci. Soc. Amer. Proc. 36: 539-543.

Tyagi, N. K., 1986. Optimal water management strategies for salinity control. Irri. and Drain. 112: 81-97.

U.S. Salinity Lab, 1954. Diagnosis and improvement of saline and alkali soils. U.S. Dept. Agr. Handbook.

Wadleigh, C. H., and A. D. Ayers, 1954. Growth and biochemical composition of bean plants as conditioned by soil moisture tension salt concentration. Plant Physiol. 20: 106-132.

Wadleigh, C. H., and H. G. Gauch, 1944. The influence of high concentrations of sodium sulfate, sodium chloride, calcium chloride, and magnesium chloride, on the growth of guayule in sand culture. Soil Sci. 58: 399-403.

Walker, R. R., E. Torokfalvy, N. S. Scott, and P. E. Kriedemann, 1988. An anlysis of photosynthetic response to salt treatment in *Vitis vinifera*. Aust. J. Plant Physio. 8: 359-374.

Yahya, A., 1998. Salinity effects on growth and on uptake and distribution of sodium and some essential mineral nutrients in sesame. J. Plant Nutri. 21: 1439-1451.

Yeo, A. R., and T. J. Flowers, 1986a. Salinity resistance in rice (*Oryza sativa* L.) and a pyramiding approach to breeding varieties for saline soils. Aust. J. Plant Physiol. 13: 161-173.

Chapter - 3

Methodology

3.1. Experimental Setup

Eighteen columns were constructed using plastic column of 100 cm high and 56 cm diameter. Three 12 mm diameter holes were drilled on one side of each column at three depths. These holes were used to insert suction lysimeters. The suction lysimeters were constructed by attaching a 60 cm long, 12 mm diameter plexi-glass tubing to a 1.5 cm diameter x 7 cm long porous ceramic cup (model # 0655x 01-B01M3, soilmoisture Equipment Corp; Santa Barbra, CA). The suction lysimeters were installed at 30^0 angle during the filling of the columns with the porous ceramic cup located at the center of the column. The end of the suction lysimeter stems was covered with rubber stoppers. Lysimeters were used to extract soil pore water to monitor EC. During sampling, the rubber stopper cover was removed first, any water accumulated in the lysimeter was removed with a syringe. A vacuum pump is then attached to the lysimeter for 5 to 15 minutes depending on the water content in the column. The water extracted in the lysimeter is then collected by a syringe and analyzed.

A 5 cm layer of gravel (~12 mm diameter) was placed at the bottom of each column. A 5 cm diameter and 150 cm high PVC pipe was placed standing near the sidewall of the columns, with the lower end in the gravel layer. The PVC pipe was used for monitoring CT water level in the columns as well as for addition/ removal of CT water from the column to maintain the CT water level at the desired depth. Air dry tailings sand (received from Syncrude) was placed on top of the gravel layer to a depth of 65 cm. Reclamation material, consisting of a soil-peat mixture (received from Syncrude), was placed on top of the tailings sand to a depth of 30 cm. Three suction lysimeters were inserted in the holes at 30^0 angle through the side-wall of the column and were sealed from inside and outside of the column with epoxy. The first suction lysimeter was placed in the middle of the reclamation material layer, second at the interface of reclamation material/sand, third at 30 cm below the interface and the fourth one was placed 60 cm below the interface (Figure 3.1).

3.1.1. Growth chamber condition

The experiment was conducted in a growth chamber where day/night temperature was set at 25°C/18°C and the photoperiod was set for 16 hours.

3.2. Treatments

The treatments consisted of three levels of CT water (0, 30, 60 cm from the reclamation material/ sand interface), two plant species (dogwood and highlander grass), and two irrigation rates simulating wet/dry conditions. Thus a total of 12 (2 plant species, 3 CT water levels, and 2 watering rates) treatments were used. Dogwood seedlings were planted in 9 randomly selected columns making sure that one column received one set of combination of the treatments (CT water level at the interface receiving high irrigation and CT water level at the interface receiving low irrigation). Seeds of highlander grass were planted in the remaining 9 columns. Due to space limitation, not all the treatments were replicated (Table 3.1). Columns were arranged in two rows in the growth chamber. Treatments receiving high irrigation were arranged in one row and low irrigation in the other row (Figure 3.1b).

3.2.1. CT water levels

CT water was pumped through the standing PVC pipe directly to the bottom of the columns in seven increments, allowing time (a week) for equilibrium and redistribution between successive additions. CT water was filled to the desired level in the columns, i.e. 0 cm, 30 cm, and 60 cm below the soil/ sand interface. These levels were monitored through the PVC pipes and maintained constant throughout the experiment by addition and removals of CT water.

The CT water level in the columns was measured with a thread tied at one end to a piece of dry clay. The thread was marked for the desired depth of CT water. The clay was lowered into the standing PVC pipe to the marked depth. If the clay just touched

CT water, the CT water was at the correct level and no CT water was added or removed. The length of the wet mark on the clay indicated the depth of CT water that needed to be removed. If there is no watermark on the clay, the thread is lowered further to determine the depth of CT water and amount of CT water that need to be added to bring water table to desired depth. The amount of water needed per mm change in CT water level was first calculated based on cross sectional area of the column and estimated porosity of the tailings sand. During the experiment, this was adjusted from experience. The CT water level was monitored and adjusted, as needed, weekly when plants were receiving irrigation water and every alternate day during drought periods when no irrigation water was applied. Amount of CT water added to each column, in order to maintain constant CT water table were recorded and later correlated to the total mass of salt accumulated in the soil profile at the end of the experiment

3.2.2. Plant species

Two plant species were selected for this study. Dogwood (*Cronus stolonifera.* Michx.), which has been found a salt tolerant shrub species and also native to the Fort McMurray area (Renault et al, 1999), and highlander grass (*Elymus trachycaulus subsp. Trachycaulus*). For dogwood, seedlings were transplanted into 9 randomly selected columns (3 seedlings/column) on 2nd November, 1999. At the time of planting, care was taken to ensure that seedlings planted in the columns were of uniform size. Ten grams of the highlander grass seeds were evenly divided and sowed in the remaining 9 columns on 4th November, 1999.

3.2.3. Irrigation

Two irrigation schemes, 3 mm/application and 6 mm/application were used to simulate dry and wet conditions respectively. These rates were selected on the basis of soil evaporation test performed in the growth chamber. Dogwood received water every alternate day and highlander grass received water every third day. The two different irrigation rates were selected for the two plant species because dogwood needed more water to meet the water demand because of their larger leaf area. Rate of transpiration have been found to be greater in the plants with larger leaf area (Kramer,1983). Irrigation water was not applied everyday to prevent the waterlogging condition in columns. Fertilizer, dissolved into the irrigation water at a concentration of 80 mg/l of nitrogen and 20 mg/l of phosphorus was applied once every month starting from 2nd December, 1999. Addition of fertilization in the saline soil has been shown to overcome some of the inhibitory effects of salinity (Heimann, 1985). No fertilizer was applied during the drought periods.

3.2.3.1. Drought periods

The experiment was run for two drought periods by withholding the irrigation water and fertilizer in order to monitor the salt migration and survival of the two plant species on the saline CT water alone. The first drought period was run for a very short period of 16 days starting from 11th August 2000 to 27th August 2000. A second, longer drought period was used to check the maximum duration of drought these plant species could survive just on the CT water. The second drought period was run for 66 days from 9th October 2000 to 15th December 2000. Recovery was monitored after resuming the application of irrigation water by measuring EC of the soil pore water, plant water potentials and photosynthesis.

3.2.3.2. Sampling at the end of the experiment

Columns were sampled at the end of the experiment. The plants were first harvested for leaf area and above ground biomass measurements. The columns were then divided into four equal quadrants. From each quadrant, a 10 x 10 x 10 sample of the reclamation material (soil peat mix used as surface soil) was taken. Two diagonally opposite samples were used for the bulk density and volumetric water content analyses and the other two samples were used for roots analyses.

The remaining surface soil was then removed to expose the tailings sand below. A 30 cm layer of tailings sand was also removed. The exposed surface was then divided into four quadrants. Undisturbed core samples (8 cm x 4 cm) were then taken from the center of the four quadrates. Two diagonally opposite samples were used for the bulk density, volumetric water content, and EC analyses and the other two samples were used for the roots analyses. For treatments where the CT water level was at the soil/sand interface, samples were only used for root analyses. Bulk densities for the treatments with CT water level at soil/sand interface were taken from the bulk density of the other treatments where CT water level was 60 cm below the interface. After sampling, a further 30 cm layer of tailings sand was removed. Exposed CT water on the surface was first removed from top and then core samples (8 cm x 4 cm) were then taken from the center of the four quadrants. Samples were analyzed as the same way as the samples below 30 cm from interface. All the samples collected were kept in Ziploc bags and stored in a cold room (4^0 C) until they were analyzed.

3.3. Analyses

Analyses conducted during the experiment include monitoring of EC of the soil pore water sampled with suction lysimeter, plant leaf water potential, leaf osmotic potential, rate of photosynthesis, leaf area, and shoot dry weight. Analyses conducted at end of the experiment on soil samples collected at three depths are bulk densities, gravimetric water content, electrical conductivities, and root length, root volume, and root dry weight. Shoot dry weight and leaf area of plants harvested at the end of the experiment were also measured.

3.3.1. Electrical conductivity analyses

3.3.1.1. During the experiment

During the experiment, the movement of salt in the soil profile was monitored by measuring electrical conductivity (EC) of the pore water taken every month from the four lysimeters. Plastic tube (0.5 mm diameter) was inserted in the needle of a syringe, which was then allowed to put in the tube of the lysimeter until it touched the cup of the lysimeter. All the pore water was then remove with the syringe. Suction was applied by connecting the tube with the vacuum pump by a tube for 5 to 15 minutes depending on the moisture content in the profile. The electrical conductivity of the pore water samples was measured with an electrical conductivity bridge (YSI model # 31, Yellow Springs Instrument Co. Inc., Yellow Springs OHIO).

3.3.1.2. End of the experiment

3.3.1.2.1. Bulk density and water content ---- Gravimetric water content and bulk density were determined using soil samples (10x10x10 cm for surface soil and 4 cm diameter x 8 cm height core sample for tailings sand). The moist weights of the samples were first measured. The samples were then dried in an oven (105°C) for 24 hours, after which dry mass of the sample were determined. Gravimetric water content was calculated by

$$\theta_m = (Mo- Md) / Md$$

where, Mo is moist weight of the sample, and Md is dry weight of the sample. Bulk density was calculated by

$$\rho b = Md / V$$

where, V is the volume of the soil sample.

3.3.1.2.2. EC analysis ----At the end of the experiment, electrical conductivity (EC) of the soil samples was measured by the saturated paste extraction method. Soil samples were first dried in oven at 115°C for water content and bulk density measurement. Afterwards, the dried soil samples were mixed thoroughly. A known weight of sub-sample (approximately 40 to 100 gm) was taken. Water was added in small increments and the soil sample was mixed after each addition. The process is continued until free water appears at the surface. The saturated soil paste was then placed in a vacuum extractor with Whiteman filter paper # 1 to extract water for EC analysis. The EC measured from the saturated paste extract was converted to EC of soil pore water by applying a dilution factor.

$$EC_{pw} = EC_{sp} \times \frac{W_{sp}}{\theta_m}$$

Where W_{sp} is gravimetric water content of the saturated paste, and θ_m is the gravimetric water content of the soil sample.

3.3.1.2.3. Salt concentration ----The amount of salt in the soil column was calculated from EC of pore water and volumetric oil water content. The salt concentration in the pore water was calculated using the relationship (Dudas, 2001).

$$C_{pw}\ (\mathrm{mg/L}) = EC_{pw}\ (\mathrm{dS/m}) \times 640$$

Where, C_{pw} is the salt concentration in the soil pore water, and EC_{pw} is the EC of the soil pore water. The total mass of salt (M) within a soil layer, with a depth of Δz, was calculated by

$$M\ (\mathrm{mg/m^2}) = C_{pw}\ (\mathrm{mg/L}) \times \theta_v \times \Delta z\ (\mathrm{cm}) \times 10$$

Where, θ_v is volumetric water content, the factor 10 converts the unit to mg/m^2. Total amount of salt in the soil column was calculated as the sum of salt mass in all soil layers.

3.3.2. Leaf water potential (Ψ_w)

Presence of salt in the soil solution decreases the water uptake by plant roots thereby decreases the plant water potential (Kramer, 1983). Therefore, measurement of plant water potential is an important parameter to monitor the adverse effect caused by salt in the soil. Plant leaf water potential (Ψ_w) was measured once in a month in the beginning of the experiment and weekly during the drought periods with a Scholander pressure chamber (**PMS** instrument Co., Corwallis, Oregon, USA). Measurements were done between 10 AM to noon on fully exposed, mature, but not old leaves. These conditions were important because the time of measurement, location of leaf, exposure and age of leaves affect both the water content and water potential measurements (Kramer, 1983). For each column, 5 leaves were selected randomly for measurements.

A selected leaf was first wrapped with SARAN WRAP to prevent water loss during measurement. The leaf was then cut from the petiole with a razor blade and put immediately to the pressure chamber with the cut surface protruding. Pressure was applied slowly to the pressure chamber from a tank of compressed N_2 until xylem sap appeared at the cut surface. The pressure applied at this point was recorded as water potential of the leaf (Kramer, 1983). The five measurements for each column were averaged.

3.3.3. Osmotic potential measurement (Ψ_s)

Decrease in plant water potential due to salinity causes decrease in the plant's osmotic potential in order to maintain the turgor potential (osmotic adjustment). Osmotic potential is an important parameter of plant water relations. After plant water potential measurement (Ψ_s) was completed, five leaves were cut and placed immediately in airtight plastic tubing and frozen in dry ice. At the time of measurement, these leaves were thawed on a lab bench for two hours and cell sap was extracted. The extracted sap was used in the osmotic potential measurement with a vapour pressure osmometer (VAPRO, model # 5520, MANDEL Scientific Co. Ltd., Utah, USA). The osmometer was calibrated with standard KCl solutions of 100, 290, and 1000 μ mol/Kg osmolality. The results obtained were in μmol/Kg, which was then converted into MPa using the van't Hoff's equation, $\Psi_s = CRT$ (Scott, 2000), where C is the solute concentration (osmolality), R is the gas constant (8.314 J K^{-1} mol^{-1}) and T is temperature in kelvin.

3.3.4. Turgor potential (Ψ_p)

Turgor potential is important for cell enlargement, stomatal opening and permeability to water and ions (Kramer, 1983). Turgor potential (Ψ_p) was calculated by subtracting osmotic potential (Ψ_s) from the water potential (Ψ_w) (Kramer, 1983).

3.3.5. Rate of photosynthesis

Rate of photosynthesis was measured on 5 randomly selected leaves from each column. The leaves were selected on the basis of maturity and position. All leaves selected were young, fully mature, and facing toward the light. The analysis was done by a photosynthesis analyzer (model # 6400, LI-COR Inc., Nebraska, USA). For dogwood, a single leaf was used for each measurement, covering the 6 cm^2 area of the leaf chamber. For highlander grass, length and width of the selected leaf covered by the leaf chamber was measured, and used to convert the measured photosynthesis rate to per unit leaf area.

3.3.6. Leaf area and above ground dry weight production

Leaf area was measured both during and at the end of the experiment. For grass, 6 cuts were done during the experiment. In addition, above ground portion was harvested at the end of the experiment. Each time the grass was cut, a sub sample of freshly cut leaves, approximately 5 gm grass was taken from each column and area was measured using a leaf area meter (Model 3100, LI-COR Inc., Nebraska, USA). After leaf area measurement, the sub sample was dried in an oven at 65°C for 24 hours and the dry weight was recorded. Leaf density (g/m^2) was calculated from the leaf area and dry weight of the sub sample. The total dry weight of the harvested grass was also measured. Total leaf area was calculated from total dry weight and leaf density. For dogwood, some branches from each column were trimmed during the experiment (a total of 4 cuts) because of the limited space in the growth chamber. Each time the total dry weight of the leaves and stems of the trimmed branch were also measured. Leaves were dried at 65°C for 72 hours and stems were dried at the same temperature for one week. Leaf area was measured using the same procedure. These were added to the leaf area and shoot dry weight measured at the end of the experiment to get total leaf area and above ground dry weight production during the experiment.

3.3.7. Root analyses

Soil samples collected at the end of the experiment were washed by hand under running tap water and roots were collected for analyses. The roots were kept in 90% ethanol, which were stored in the cold storage (4 °C temperature) before measurements. After all the measurements were completed, root dry weight was measured on the same samples.

3.3.7.1. Root volume ---- Root volume was measured by the water displacement method. Water was filled in a measuring cylinder up to the top and then roots (dried with tissue paper) were put carefully into the cylinder. Water displaced by roots was collected in the container in which the cylinder stood. The volume of displaced water was measured and recorded as root volume.

3.3.7.2. Root length ---- Root length was measured by Image analysis (Win RHIZO 2001A), and an HP scanner. Cleaned roots were blotted dried by tissue paper and spread in a shallow dish (14 cm length and 8.8 cm width) containing water. Roots were carefully floated apart with the help of a needle to minimize overlapping. These roots were then scanned by the HP scanner and the image used for root length measurements.

3.3.7.3. Root dry weight — Washed roots were kept in the oven at 65^{0}C for 24 hours. Dry mass was recorded.

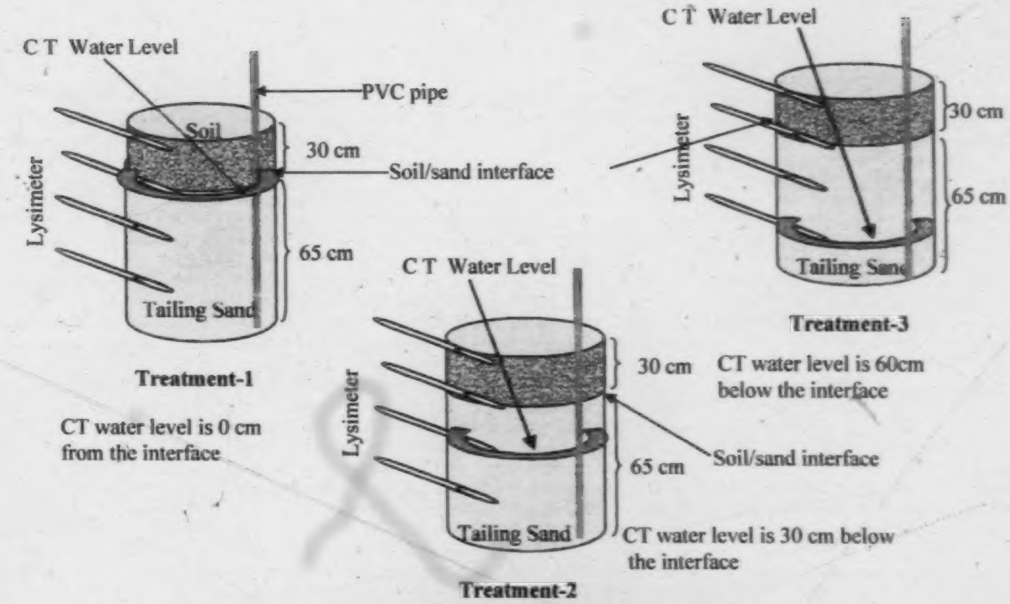
3.3.8. Statistical analysis

Statistical analysis of all the data collected from the measurements was done using General Linear Model procedure of SAS (SAS Institute, 1990). Means were compared using the Least Significant Difference at 95% confidence level.

Two plants species were analyzed separately. The statistical design used was a split plot design. The statistical model used was as follows

$$Y_{ijk} = \mu + \tau_i + \rho_k + W_{ik} + \beta_j + (\tau\beta)_{ij} + E_{ijk}$$

Where μ is the overall experimental mean, τ_i represents CT water level (fixed factor A), β_j represents irrigation rate (fixed factor B), $(\tau\beta)_{ij}$ represents CT water levels by irrigation rate interaction. E_{ijk} represents residual error.


C T Water Level
PVC pipe
Soil
30 cm
Soil/sand interface
Lysimeter
65 cm
Tailing Sand
Treatment-1
CT water level is 0 cm from the interface
C T Water Level
Lysimeter
30 cm
Soil/sand interface
65 cm
Tailing Sand
CT water level is 30 cm below the interface
Treatment-2
C T Water Level
Lysimeter
30 cm
65 cm
Tailing Sand
Treatment-3
CT water level is 60cm below the interface

(a)

(b)

Figure 3.1. (a) The experimental set up of the columns. Three columns are shown to represent three depths of CT water levels. (b) Photograph of the columns with dogwood and highlander grass in a growth chamber.

Table 3.1. Distribution of treatments (CT water level and irrigation rate to dogwood and highlander grass)

CT Water Level (cm)*	Irrigation			
	Dogwood		Highlander Grass	
	High**	Low***	High**	Low***
0	x	x	xx	xx
30	xx	xx	x	x
60	x	xx	xx	x

*CT water level from the soil/sand interface
**High 6 mm/application
***Low 3 mm/application
Treatments marked with x are not replicated

Treatments marked with xx has two replications

3.4. References

Dudas, M. J., 2001. Environmental Soil Chemistry, Lecture note. Department of Renewable Resources. University of Alberta. Edmonton. Alberta. Canada.

Heimann, H., 1958. Irrigation with saline water and the ionic environment. Potassium Symp. 173 - 220.

Kramer, P. J., 1983. Water relations of plants. Academic Press, New York.

Renault, S., E. Paton, G. Nilsson, J. J. Zwiazek, and M. .D. MacKinnon, 1999. Responses of boreal plants to high salinity oil sands tailings water. J. Environ. Qual. 28: 1957-1962.

SAS Institute Inc., 1990. SAS users guide: statistics SAS Institute Inc., Cary, N.C.

Scott, H. D., 2000. Soil Physics: Agricultural and Environmental Applications. Iowa State University Press, Ames.

Chapter - 4

Electrical Conductivity and Salt Distribution in Capped Composite Tailings

4.1. Introduction

Oil sand mining operations at Syncrude Canada Ltd. result in the production of large volume of fine tailings. Current tailings management includes the containment of fine tailings within settling basins, and the production of a material known as composite tailings (CT) (Matthews et al., 2000). Composite tailings are produced by mixing the sand fraction of the tailings with mature fine tailings and gypsum (as a chemical flocculant) at the rate of 750 - 1200 g/m^3 of tailings (Sego et al., 1993). Water released after the self-weight consolidation of CT is known as CT water. CT water is saline and therefore not suitable for the terrestrial reclamation. Capping of the composite tailings with tailings sand and then surface soil material is one of the possible reclamation techniques that can be implemented for re-vegetation on CT (MacKinnon, 2000). However, because of the high salt content of the CT water (Renault et al., 1998), it is necessary to prevent excessive accumulation of salt and other dissolved chemicals from the CT water in the root zone to ensure long-term sustainability of the ecosystem developed on reclaimed CT.

When CT is capped by tailings sand and the soil material, salt movement is controlled by the rate at which salty CT water is released as a result of slow consolidation of the CT deposit and the depth of CT water in the soil profile. Salt movement is also controlled by the environmental conditions to a great extent, which include precipitation and temperature. As salt is moved up by the capillary action in the soil profile, it accumulates at the soil surface after water evaporates. Leaching of that deposited salt down the profile is important to prevent the problem of salinity (Slation et al., 1994). Therefore, frequency and the amount of rainfall plays a significant role in determining the fraction of salt leached, and the amount of salt accumulation in the soil profile.

Since water and salt movement depends to a great extent on water uptake by plants, and on the rooting depth and root distribution (McNeal et al., 1970), selection of plant species for reclamation is an important factor. Dogwood (*Cronus stolonifera*. Michx.) is a salt tolerant shrub species and also native to the boreal forest (Renault et al., 1999). Highlander grass (*Elymus trachycaulus* subsp. *Trachycaulus*) is also native to that area. However, effects of saline soil on the growth and survival of highlander grass has not been specifically studied.

In this chapter, I evaluate salt movement and salt distribution in the soil profile consisting of CT - tailings sand - surface soil. Particularly, the effects of CT water level depth, precipitation (which is simulated with different rates of irrigation), and plant species were evaluated.

4.2. Materials and methods

Eighteen columns were constructed and filled with the tailings sand (bottom 65 cm) and the reclamation material (top 30 cm). CT water was filled to the designed depths (i.e., 0, 30, or 60 cm from the soil/sand interface) and was kept constant throughout the experiment by adding/ removing the CT water to/from the columns. Dogwood seedlings were planted in 9 randomly selected columns and highlander grass was grown in the remaining 9 columns. Two irrigation rates (3 mm/application and 6 mm/application) were applied to both plant species. The experiment was run for two drought periods by withholding irrigation water. The short drought period was run from 11th August 2000 to 27th August 2000 (for 16 days) and the long drought period was run from 9th October 2000 to 15th December 2000 (for 66 days). Soil pore water was extracted monthly using suction lysimeters installed in the columns, and was analyzed for electrical conductivity. Soil samples were taken at the end of the experiment from three depths of the column. Electrical conductivity of those samples was measured by the saturated paste extraction method. The amount of salt present in the soil profile at the end of the experiment was calculated from EC and the bulk density data. Statistical analysis of the EC data was done using General Linear Model procedure of SAS (SAS Institute, 1990). Means were compared using the Least Significant Difference at 95% confidence level. Details of the experimental set up and calculation of the total salt concentration in the soil profile are presented in Chapter 3.

4.3. Results

In the results and discussion section of this thesis, irrigation rate at 3mm / application is represented by low irrigation rate and that at 6mm/ application by high irrigation. CT water level depths from the soil/sand interface have been shown by 0 cm, 30 cm and 60 cm. Results of the EC analyses are presented in three parts. The first is in the early period of the experiment (from December 1999 to July 2000), when all the plants received regular irrigation water. The second includes the drought period when no irrigation water was applied and the plants were growing solely on the CT water. The third is results from analyzing soil samples collected at the end of the experiment.

4.3.1. The early period of the experiment

Physical and chemical properties of CT water, tailings sand, and reclamation material are given in Table 4.1. EC of the CT water was measured at 4 dS/m, and that of tap water, used for irrigation, was 0.57 dS/m (Table 4.1). Results from the early period of the experiment are shown in Table 4.2. In many cases, pore water could not be collected from the suction lysimeter located in the soil layer. The EC of the pore water, collected from the bottom of the column, were higher than the EC of the CT water. There was no significant effect of time on the EC of soil pore water. There was no significant interaction between irrigation rate and CT water levels on the EC. However, low irrigation did cause an increase in the EC of soil with both dogwood and highlander grass. Treatments with dogwood and highlander grass showed increased EC in the surface soil with CT water level at the soil/sand interface (0 cm). However, in dogwood under low irrigation and CT water level at 0 cm, EC of the pore water from the soil layer was significantly higher ($p < 0.0001$) and reached as high as

6.4 dS/m (Table 4.2). Treatments with CT water level at 60 cm below the soil/sand interface showed elevated EC in the bottom of the column.

4.3.2. During the drought periods

4.3.2.1. EC of the pore water of the soil layer

4.3.2.1.1. The first shorter drought period ---- During the first drought period (16 days), soil pore water could not be collected from the treatments with CT water levels at 30 cm and 60 cm below the soil/sand interface. Therefore, the results presented in Figure 4.1 include data from the treatment with CT water level at the soil/sand interface. In all cases, EC increased with time. However, high irrigation applied to dogwood kept the EC below that of the CT water (Figure 4.1a), whereas in highlander grass EC did not exceed that of CT water (Figure 4.1b) regardless of irrigation rate. In both dogwood and grass, treatments with low irrigation showed greater increase in the EC values, as for example, from 4 dS/m to 4.8 dS/m in dogwood and from 3.5 dS/m to 3.9 dS/m in case of highlander grass. In dogwood, the difference in the EC of the pore water is not significant with respect to irrigation rate. In highlander grass, EC in the surface soil was below 4 dS/m despite the increase in the EC of the pore water,

4.3.2.1.2. Second longer drought period ---- EC of the soil pore water in the soil layer of the treatment with dogwood showed no significant difference with the irrigation rate. However, low irrigation did cause a slight increase in the EC value. Low irrigation kept the EC of the soil pore water above the EC of the CT water.

In treatments with highlander grass, EC increased from 3.2 dS/m to 4.6 dS/m at low irrigation as compared to from 2.8 dS/m to 3.5 dS/m at high irrigation (Figure 4.1b). High irrigation did prevent an increase in EC, and kept it below the EC of the CT water. At the resumption of irrigation, EC decreased considerably in both the treatments demonstrating leaching of the accumulated salt and/or dilution of the accumulated salt by irrigation water.

4.3.2.2. EC of the pore water from the soil/sand interface

4.3.2.2.1. First shorter drought period ---- In dogwood, electrical conductivity of soil pore water at the soil/sand interface was increased with time in all the cases (Figure 4.2), except treatment with high irrigation and CT water level at 30 cm and 60 cm. Treatments with CT water levels at 0 cm and low irrigation rate, showed elevated EC and was higher with dogwood (Figure 4.2a) than with grass (Figure 4.2b). No significant difference with the irrigation rate was found in the EC value when the CT water level was at 0 cm. However, treatments with CT water level at 30 cm below the interface showed significantly higher EC at low irrigation. Treatments with highlander grass recorded EC consistently lower than that of CT water (Figure 4.2b). Application of irrigation water at the end of the drought period did reduce the EC of soil with both dogwood and highlander grass. Highlander grass showed the full recovery, whereas dogwood showed 50% recovery with the exception of dogwood under low irrigation and CT water level at 30 cm (100% recovery).

4.3.2.2.2. Second longer drought period ---- EC of the pore water from the treatment with dogwood increased with time, however, increase in the EC was not significant after October. Within the same CT water level, low irrigation caused a greater increase in EC than high irrigation. In case of dogwood, CT water level at the soil/sand interface showed higher EC than EC of the CT water. Dogwood, under low irrigation and CT water level at 30 cm, showed similar result. However, high irrigation and low CT water level kept the EC lower than that of CT water.

EC of the pore water from the treatment with highlander grass increased with time in the absence of irrigation water. Because of the lack of sufficient moisture, EC was not measured from the column with CT water level at 60 cm below the interface. In all cases, application of irrigation water at the end of the drought period caused a decrease in the EC value, indicating the dilution of the accumulated salt.

4.3.3. EC analyses at the end of the experiment

4.3.3.1. Surface soil

Results of the EC analysis of the soil sample are shown in Figure 4.3. There is a significant interaction between the CT water level and irrigation on the EC of the soil in dogwood ($p = 0.002$). However, highlander grass showed no such effect ($p = 0.267$). CT water level alone had significant effect on EC of the highlander grass ($p < 0.0001$), whereas irrigation had no significant effect ($p = 0.67$). EC in highlander grass was significantly higher than in dogwood ($p = 0.0002$).

EC of the samples collected at the end of the experiment from the treatments with dogwood receiving high irrigation and CT water level at 60 cm depth recorded the lowest EC (0.6 dS/m), and CT water level at 0 cm and low irrigation showed the highest EC mean value (6 dS/m). EC of the soil pore water from the treatment with CT water level at the soil/sand interface showed higher value than EC of the CT water (Figure 4.3). Lowering of the CT water level seemed to decrease the EC value in the soil layer irrespective of the irrigation rate (Figure 4.3).

Soil pore water from the treatments with highlander grass showed higher EC in the surface soil in treatment with high CT water level and low irrigation (6.4 dS/m) as compared to the treatment with same water levels but high irrigation (4.7 dS/m). Within the same CT water levels, low irrigation resulted in higher EC value than high irrigation (Figure 4.3), however, the difference was not significant. EC of the soil pore water from the treatment with CT water level at the soil/sand interface and 30 cm below the interface showed higher value than that of the CT water. However, CT water level at 60 cm below the interface seemed to prevent salt accumulation in the soil layer irrespective of the irrigation rate (Figure 4.3).

4.3.3.2. Between 30 - 60 cm depth

Results of the EC analysis of the soil sample taken from 30 - 60 cm depth of the soil profile are shown in Figure 4.3. There is a significant interaction between the CT water level and irrigation on the EC of the soil with dogwood. However, treatment with highlander grass showed no such effect ($p = 0.66$). CT water level and irrigation alone had significant effect on EC of the highlander grass ($p < 0.0001$ and 0.019

respectively). Treatments with highlander grass showed significantly higher EC than those with dogwood ($p = 0.0053$).

Samples collected at the end of the experiment from the treatment with dogwood with CT water level at 60 cm depth and high irrigation recorded the lowest EC (0.8 dS/m). However, same water level but low irrigation caused a significant increase in the EC value (3.8 dS/m). EC of the pore water from the column with highlander grass showed the similar trend as with dogwood.

4.3.3.3. Between 60 - 90 cm depth

Results of the EC analysis of the soil sample taken from 60 - 90 cm depth of the soil profile are shown in Figure 4.3. There is a significant interaction between the CT water level and irrigation on the EC of the soil in dogwood ($p = 0.0019$). However, highlander grass showed no such effect ($p = 0.27$). Water level and irrigation alone had significant effect on EC of the highlander grass ($p = 0.0021$ and 0.0006 respectively). Highlander grass showed no significant difference from dogwood ($p = 0.27$). EC of the pore water in all the cases showed higher EC than EC of the CT water.

4.3.3.4. Salt distribution in the soil/sand column

Total amount of salt in the soil profile was calculated using measured soil EC, water content, and bulk density for each depth (see Chapter 3 and Appendix A1). Results are shown in Figure 4.4. CT water levels and irrigation had significant effect on salt accumulation in the soil profile ($p < 0.0001$).

In dogwood, salt concentration in soil increases with increasing the CT water level. Irrigation had significant effect on the salt accumulation in the soil layer ($p = 0.005$). Low irrigation resulted in higher salt concentration (Figure 4.4). Salt concentration between 30 - 60 cm depth of the soil profile decreased with the CT water level depth, however, the difference was not statistically significant ($p = 0.54$). Salt concentration in the bottom of the column i.e., between 60 - 90 cm depth of the soil profile, was found to be affected by the CT water level depth under high irrigation, whereas, low irrigation did not show similar results. Under high irrigation, salt concentration in the profile increased with decrease in the CT water level depth. Interestingly, for treatments with CT water levels at 30 cm and 60 cm, very little salt was found in the surface soil. There is a sharp decrease in the salt concentration in treatment with CT water level at 60 cm depth.

In highlander grass, salt concentration in soil layer increases with increasing CT water level. Irrigation had significant effect on the salt accumulation in the soil layer ($p = 0.003$). Low irrigation and CT water level at 0 cm showed the maximum salt accumulation (Figure 4.4). Accumulation of salt in the second depth i.e., between 30 - 60 cm depth, was unaffected by the CT water level and the irrigation rate. Major fraction of salt was found in the bottom of the profile i.e. between 60 - 90 cm depth. CT water level and irrigation rate had no significant effect.

4.3.4. Salt Balance

It is evident from the electrical conductivity analyses of the soil samples collected at the end of the experiment that salt accumulated in the soil profile. Total salt content in the profile was calculated by adding calculated salt content in three layers (soil, 0 - 30 cm from the interface, and 30 - 60 cm from the interface). As CT water is extracted by plants, and/or evaporates from soil surface, salt is left behind and accumulate in the soil. Total CT water added to the columns during the experiment in order to maintain constant CT water level is assumed to be equal to CT water used by plants and evaporated from the soil surface. This is correlated with total salt content in the soil profile. Results are shown in Figure 4.5. There was a stronger correlation between the CT water used and total salt concentration in treatment with highlander grass ($R^2 = 0.736$) than in column with dogwood ($R^2 = 0.335$) (Figure 4.5).

4.4. Discussion

4.4.1. In the early period

In the early period of the experiment, EC of the soil pore water was close to the EC of the CT water. CT water used during this period was also very low (Table 4.5) since applied irrigation water was sufficient to meet plant water requirement. EC in the bottom of the column was higher than the EC of the CT water (Table 4.1). The higher EC value in the bottom of the column might be due to selective use of water and subsequent leaching of the accumulated salt in the soil/sand column, which might have caused an accumulation of salt in the bottom of the column. CT water level at 0 cm did cause an increase in the EC value in the soil surface. The increase in EC in the soil surface might be due to the high level of CT water, which caused the CT water to move up by capillary rise. Thus, CT water level at the soil/sand interface seemed to accumulate salt even if irrigation water or rainfall (field condition) is applied when dogwood is grown. However, highlander grass did seem to prevent salt accumulation in the surface soil.

4.4.2. During the drought periods

During both drought periods, samples from the dogwood could only be collected from treatment with CT water levels at 0 cm. CT water levels at 30 cm and 60 cm below the soil/sand interface provided a capillary break, which might be due to the fact that CT water did not move far enough and therefore, not enough moisture was available which, might have created an opportunity for roots to grow deeper in order to get moisture (MacKinnon, 2003). However with grass, CT water did move up to the rooting zone when the water level was at 30 cm below the interface. The greater upward movement of CT water might be due to the faster roots growth and more profuse root growth of highlander grass (Chapter 6). Another possible reason behind the greater upward movement of the CT water in treatment with highlander grass might be due to the soil compaction, which, was recorded during the experiment (Table 4.6), which brought down the thickness of the cap.

The first drought period, which was run for 16 days showed an increase in EC irrespective of the CT water depths and irrigation; however, low irrigation resulted in higher EC than high irrigation. The increase in EC at low irrigation indicates an accumulation of salt after water was taken up by the plant roots, leaving the salt dissolved in the soil solution behind. The selective use of water is because of the semi-permeable nature of the root cell membrane (Nobel, 1999).

The second and longer drought period, which was run for 66 days, showed an increase in the EC values of the samples collected from the soil layer. In the absence of external supply of water, salts of the CT water moved up by capillary rise and after water is used by plants, depositing dissolved salt in the soil layer. However EC of the samples from the interface layer showed a slightly different trend. After the start of the drought period, EC increased in all the cases and then stabilized. This can be explained by the mechanism of the salt movement proposed by Todd and Kemper (1972). As salts move upward and deposit at the evaporating surface, concentration near the surface becomes much larger than the initial concentration and a gradient is formed which causes salt to move back into the profile by the process of dispersion. Salt accumulates when upward migration of salt is faster than downward movement. Another possible reason may be the frequent addition of the CT water during the drought periods in order to maintain constant CT water level. When no irrigation water was applied, CT water was the only source of moisture for the plants growing in the columns. As CT water was selectively used by the plant roots, leaving salt in the soil, caused an increase in EC. Addition of CT water diluted the accumulated salt, and therefore brought down the EC value. At the end of the drought period EC dropped significantly representing successful leaching and dilution of the CT water upon resumption of irrigation.

4.4.3. Salt distribution in the soil/sand profile

(i) Surface soil

Both dogwood and highlander grass showed greater salt accumulation in the columns with CT water level at soil/sand interface. Irrigation rate affected the salt accumulation significantly. Low irrigation rate and CT water level at the soil/sand interface caused significantly higher salt accumulation (Figure 44.4). The greater accumulation of salt in the surface soil in treatments with low irrigation and CT water level at the interface might be because of the fact that, low irrigation rate there was not sufficient water left for leaching as most of the applied water might have been used up by the plants roots in order to meet transpiration requirement. However, high irrigation leached some fraction of accumulated salt. Also the soil is 90% peat and hence the water holding capacity is very high, therefore, more water would be needed to leach the salts out. Therefore, Low irrigation resulted in less leaching and hence higher salt content in the treatment with CT water level at the soil sand interface. At low irrigation rate, CT water being used by plants epically during the drought periods, bringing the saline CT water up in the surface soil and leaving salt.

Treatments with highlander grass showed significant effect of the CT water level. Closer the CT water level to the soil/sand interface more salt accumulated in the surface soil. Treatments with highlander grass showed greater salt accumulation than with dogwood, which might be due to more profuse root growth (Chapter 6) and plant water uptake in the lower part of the column. This also resulted in higher salt concentration as water was taken up by the roots, leaving salt behind. Significant amount of CT water was used during the drought periods, as shown by the amount of CT water that must be added to the columns in order to maintain constant CT water level (Table 4.5).

(ii) Between 30-60 cm depth

Treatments with both dogwood and highlander grass showed no significant effect of either CT water level or irrigation rate on the salt accumulation in the middle of the column (between 30-60 cm depth). However, the amount of salt accumulated in 30-60 cm depth is significantly greater that in the surface soil, indicating both capillary rise and plant uptake of CT water.

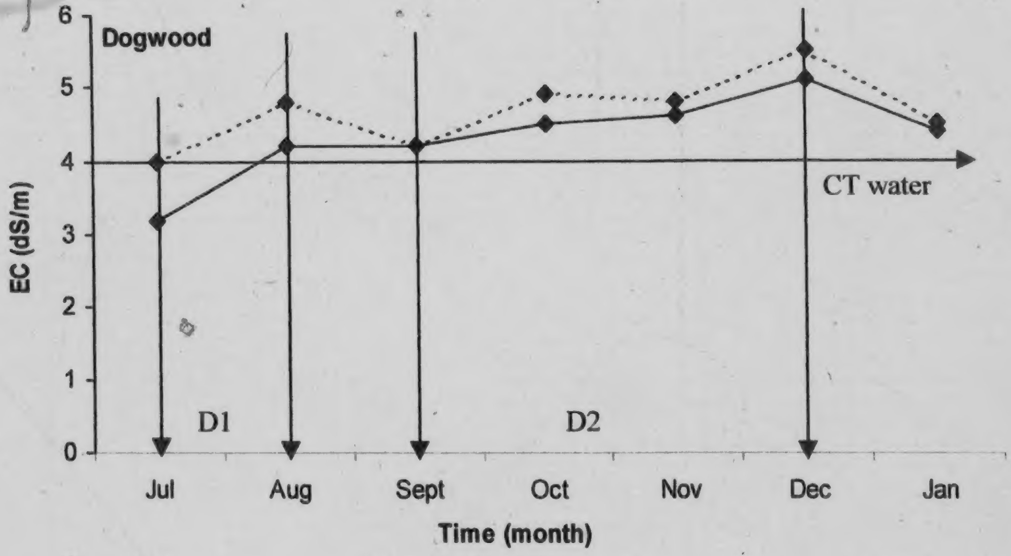
(iii) Between 60-90 cm depth

Most fraction of the salt was accumulated in the bottom of the column. Irrigation rate and CT water level had no significant effect on the salt accumulation in this depth. Most of the salt accumulated in the bottom of the columns due to frequent addition of

CT water to maintain the constant CT water level. This is supported by the data provided in Figure 4.5. Deeper root growth (in search of water, specially during drought period) (Chapter 6) and CT water uptake left the salt behind causing the salt concentration between 60-90 cm depth to increase.

4.5. Conclusion

In all treatments, accumulation of salt increased in all three depths during drought period. However, majority of accumulated salt was found in the bottom of the columns. CT water level at 0 cm was found to be unsuitable especially for dogwood, as salt was found to be accumulating in the soil layer. However, CT water level at 30 cm and 60 cm below the soil/sand interface seemed to prevent salt accumulation in the surface soil. Irrigation rate also affected the salt accumulation in the surface soil significantly. High irrigation resulted in lower salt accumulation.



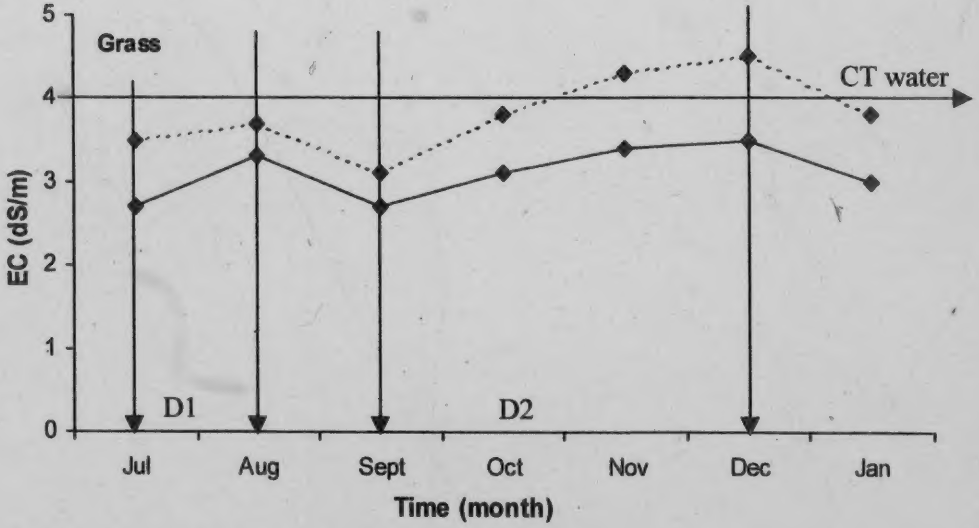
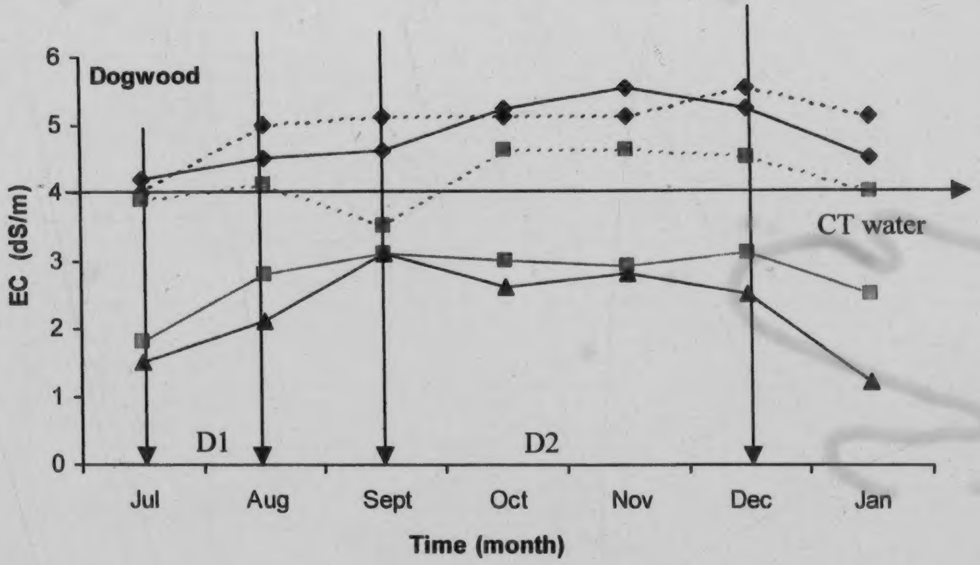


Figure 4.1. Electrical conductivity of the soil pore water collected from the lysimeters from the soil layer of treatment with dogwood and grass during drought periods. D1 and D2 represent the two drought periods. Solid line represents high irrigation and broken line represents low irrigation. Diamond is used to represent 0 cm CT water level depth.



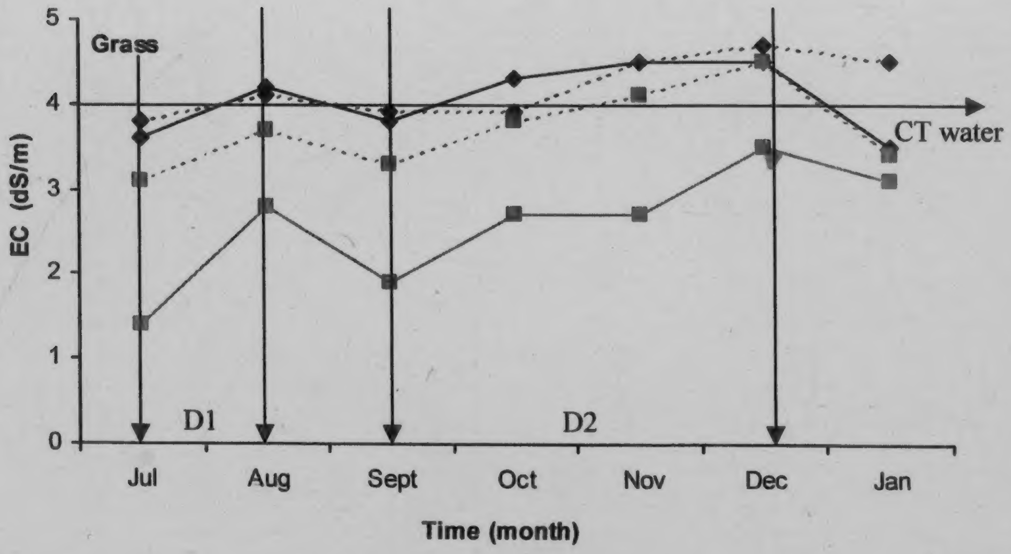
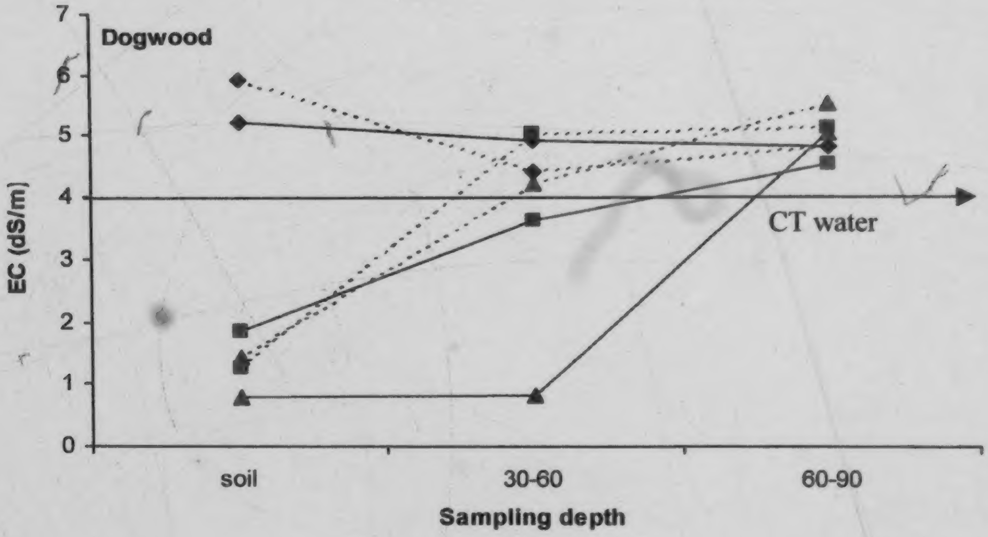


Figure 4.2. Electrical conductivity of the soil pore water collected from the lysimeters from the soil/sand interface of the treatment with dogwood and grass during the two drought periods. D1 and D2 represent the two drought periods. Solid line represents high irrigation and broken line represents low irrigation. Diamond, square, and triangle are used to represent 0 cm, 30 cm, and 60 cm CT water level depth respectively.



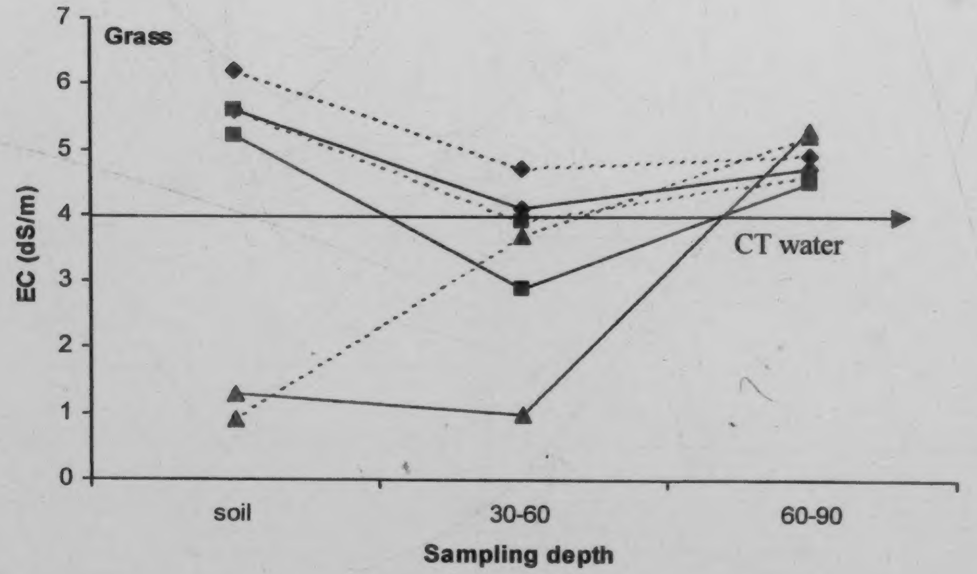
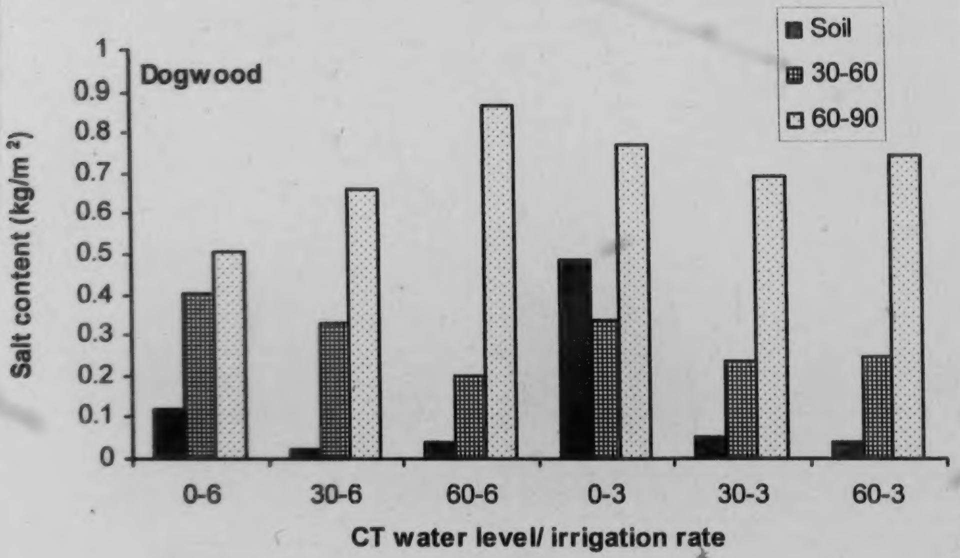


Fig 4.3. Electrical conductivity of pore water (saturated paste) of the core samples collected at the end of the experiment from the three depths of treatment with dogwood and grass. Solid line represents high irrigation and broken line represents low irrigation. Diamond, square, and triangle are used to represent 0 cm, 30 cm, and 60 cm CT water level depth respectively.



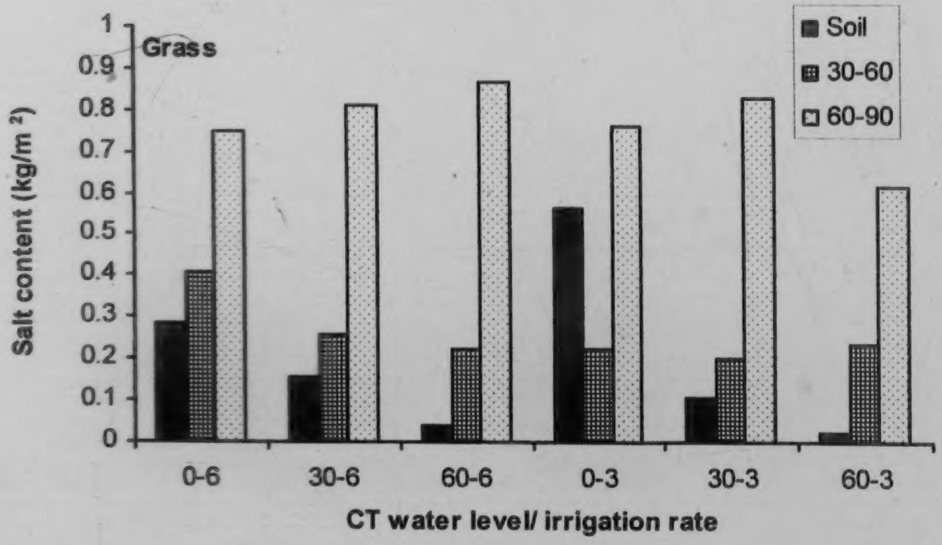
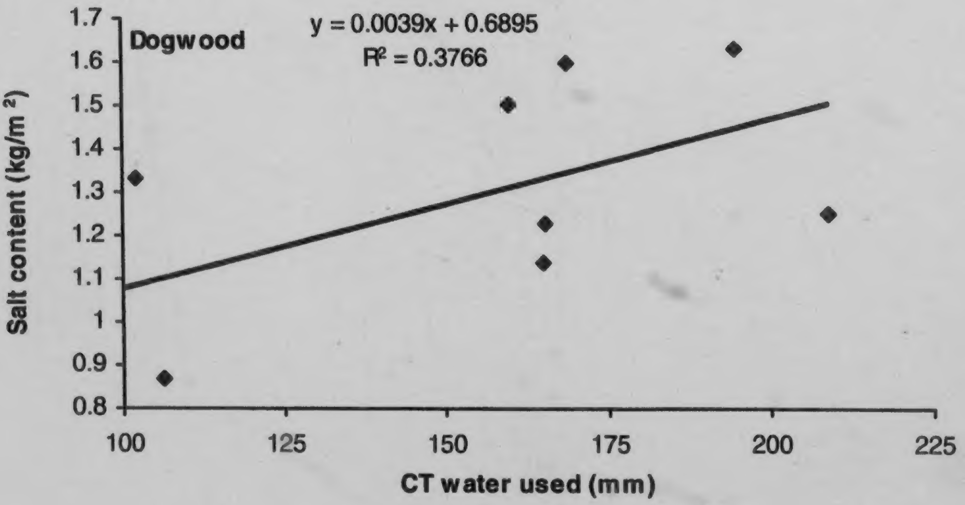


Fig. 4.4. Final distribution of salt at the end of the experiment in the three depths of the treatment with dogwood and grass.



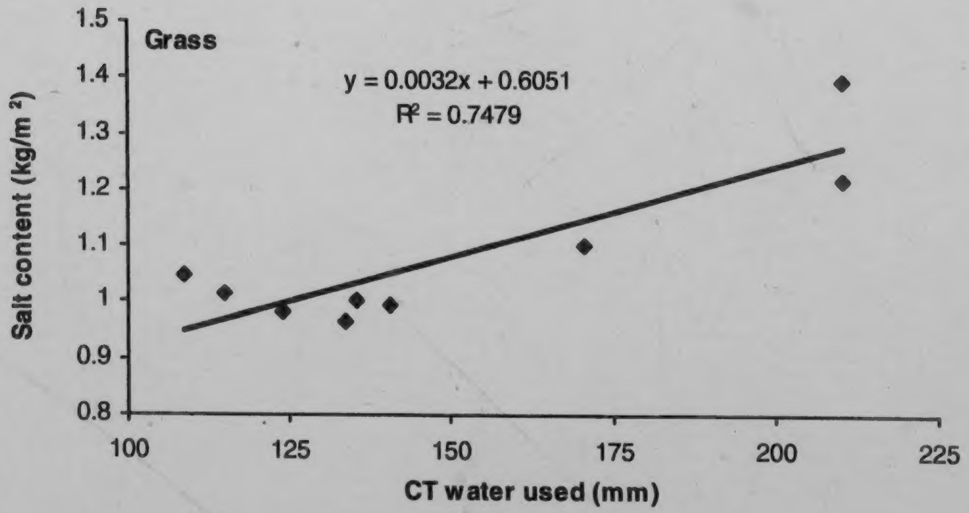


Fig 4.5. Correlation between the total salt concentration and the total amount of CT water used in the treatment with dogwood and grass.

Table 4.1. Physical and chemical properties of CT water, tailings sand and the reclamation material.

Properties	
CT water	
EC	3.98 dS/m
pH	8.0
Na^+	1190 mg/l
SO_4^{-2}	96 mg/l
Ca^{2+}	52 mg/l
Mg	30 mg/l
Tailings sand	
Hydraulic conductivity	1.89×10^{-4} m/s
Texture	Sandy loam
Bulk density	1.37 gm/cm^3
EC	0.8 dS/m
Reclamation material	
Hydraulic conductivity	2.45×10^{-7} m/s
Texture	none

Table 4.2. Electrical conductivity of the soil pore water collected in the early period of the experiment from the suction lysimeters located at four depths in the soil/sand column of dogwood. Suction lysimeter numbers 1,2,3, and 4 are used for suction lysimeter's position in the soil surface, soil/sand interface, 30 cm below the interface, and 60 cm below the interface respectively.

Date of analysis (Grass)	EC (dS/m)				**(Dogwood)**	EC (dS/m)			
Treatment	1	2	3	4	**Treatment**	1	2	3	4
23/12/1999									
0cm/6mm	*	3.7	4.5	4.7	0-6	*	4.6	4.2	4.3
30cm/6mm	*	*	*	4.6	30-6	*	*	*	4.7
60cm/6mm	*	*	*	4.3	60-6	*	*	*	4.6
0cm/3mm	*	3.4	4.4	4.4	0-3	*	4.9	4.6	4.4
30cm/3mm	*	*	*	4.6	30-3	*	*	*	4.5
60cm/3mm	*	*	*	4.6	60-3	*	*	*	4.6
23/1/2000									
0cm/6mm	*	*	4.0	4.8	0-6	*	5.3	4.8	4.9
30cm/6mm	*	*	4.8	5.1	30-6	*	*	*	5.1
60cm/6mm	*	*		4.4	60-6	*	*	*	4.8
0cm/3mm	3.9	4.7	5.0	5.1	0-3	*	6.2	5.2	5.1
30cm/3mm	*	*	*	4.6	30-3	*	1.2	5.0	5.0
60cm/3mm	*	*	*	4.6	60-3	*	*	*	4.9
23/2/2000									
0cm/6mm	2.5	3.8	4.9	5.0	0-6	*	5.3	3.9	4.9
30cm/6mm	*	2.0	5.1	5.1	30-6	*	*	4.5	5.0
60cm/6mm	*	*	4.0	5.0	60-6	*	*	*	4.9
0cm/3mm	2.6	4.5	5.0	5.1	0-3	6.4	6.0	6.0	5.9
30cm/3mm	*	*	*	4.9	30-3	*	*	5.0	5.0
60cm/3mm	*	*	*	4.9	60-3	*	*	*	4.9

*Pore water could not be collected from the suction lysimeter due to unavailability of enough moisture.

EC of CT water = 4 dS/m
EC of tap water = 0.57 dS/m

Table 4.3. Electrical conductivity of the soil pore water collected in the early period of the experiment from the suction lysimeters located at four depths in the soil/sand column of dogwood. Suction lysimeter numbers 1,2,3, and 4 are used for suction lysimeter's position in the soil surface, soil/sand interface, 30 cm below the interface, and 60 cm below the interface respectively.

Date of analysis (Grass)		EC (dS/m)			(Dogwood)		EC (dS/m)		
Treatment	1	2	3	4	Treatment	1	2	3	4
23/3/2000									
0cm/6mm	*	3.4	4.3	4.4	0-6	4.2	4.4	4.9	4.9
30cm/6mm	*	*	3.4	4.5	30-6	*	*	*	4.5
60cm/6mm	*	*	*	3.9	60-6	*	*	*	2.3
0cm/3mm	3.8	3.9	4.3	4.6	0-3	4.4	4.5	5.1	7.2
30cm/3mm	*	*	*	4.3	30-3	*	*	42	4.4
60cm/3mm	*	*	*	4.3	60-3	*	*	*	4.6
23/4/2000									
0cm/6mm	2.3	2.9	4.2	4.6	0-6	2.3	3.9	4.5	4.5
30cm/6mm	*	1.4	3.9	4.6	30-6	*	*	3.3	4.7
60cm/6mm	*	*	*	3.8	60-6	*	*	*	4.1
0cm/3mm	3.3	3.7	4.1	4.3	0-3	4.5	4.7	5.2	5.2
30cm/3mm	*	*	3.4	4.6	30-3	*	*	4.6	4.7
60cm/3mm	*	*	*	4.3	60-3	*	*	*	4.4
6/6/2000									
0cm/6mm	2.0	3.4	3.9	4.1	0-6	1.6	3.3	3.8	4.2
30cm/6mm	*	1.5	3.5	4.2	30-6	*	*	2.8	4.4
60cm/6mm	*	*	*	3.1	60-6	*	*	*	3.5
0cm/3mm	3.2	4.3	3.7	3.7	0-3	5.3	4.8	4.7	4.3
30cm/3mm	*	*	2.9	3.6	30-3	*	*	4.4	4.6
60cm/3mm	*	*	4.6	4.9	60-3	*	*	*	4.2

*Pore water could not be collected from the suction lysimeter due to unavailability of enough moisture.

EC of CT water = 4 dS/m
EC of tap water = 0.57 dS/m

Table 4.4. ANOVA summary for the EC analysis of the samples collected from three depths of dogwood and highlander grass at the end of the experiment.

Plant	Source	Pr > F Soil layer	Pr > F 30 cm. below soil layer	Pr > F 60 cm. below soil layer
Dogwood	Water level	0.0044*	0.0011*	0.0009*
	Irrigation	0.0147*	0.0375*	<0.0001*
	Water Level*Irrigation	0.0021*	0.0017*	0.0019*
Highlander grass	Water level	<0.0001*	<0.0001*	0.0021*
	Irrigation	0.6664	0.0192*	0.0006*
	Water Level*Irrigation	0.2668	0.6517	0.2739

* significant at $\alpha = 0.05$

Table 4.5. Amount of CT water used during the experiment

Treatment	Total CT water used (mm)	Total CT water used during dry cycle (mm)	% of CT water used during dry period
Grass			
0cm/6mm	183	148	82
30cm/6mm	155	130	89
60cm/6mm	78	52	68
0cm/3mm	224	164	75
30cm/3mm	130	96	75
60cm/3mm	66	56	82
Dogwood			
0cm/6mm	199	184	94
30cm/6mm	146	128	89
60cm/6mm	110	96	89
0cm/3mm	264	168	89
30cm/3mm	142	116	83
60cm/3mm	130	112	88

Table 4.6. Soil settlement from the top of the column with highlander grass.

Treatment (CT water level/irrigation rate)	Soil settlement (cm)
0cm/6mm	17
30cm/6mm	18
60cm/6mm	20
0cm/3mm	18
30cm/3mm	12
60cm/3mm	8

4.6. References

MacKinnon, M. D., J. G. Matthews, W. H. Shaw, and R. G. Cuddy, 2000. Water quality issues associated with implementation of composite tailings (CT) technology for managing oil sands tailings. Proceedings of the Sixth International Conference on Environmental Issues and Management of Waste in Energy and Mineral Production (SWEMP 2000) Calgary, Alberta, Canada. 443-453.

McNeal, B. L., J. D. Oster, and J. T. Hatcher, 1970. Composition Data As An Aid To In-situ Estimation of Soil Salinity. Soil Sci. 110: 405-414.

Matthews, J.G., W. H. Shaw, M. D. MacKinnon, and R. G. Cuddy, 2000. Development of composite tailings technology at Syncrude Canada. Proceedings of the Sixth International Conference on Environmental Issues and Management of Waste in Energy and Mineral Production (SWEMP 2000) Calgary, Alberta, Canada. 455-463.

Nobel, P. S., 1999. Physiochemical and Environmental Plant Physiology. Academic Press, San Diego.

Renault, S., C. Lait, J. J. Zwiazek, and M. MacKinnon, 1998. Effect of high salinity tailings waters produced from gypsum treatment of oil sands tailings on plants of the boreal forests. Environ. Pollution, 102: 177-184.

Renault, S., E. Paton, G. Nilsson, J. J. Zwiazek, and M. D. MacKinnon, 1999. Responses of boreal plants to high salinity oil sands tailings water. J. Environ. Qual. 28: 1957-1962.

SAS Institute Inc. 1990. SAS users guide: statistics SAS Institute Inc., Cary, N.C.

Sego, D. C., S. A. Proskin, and R. Burns, 1993. Enhancement of solid content of oil sands fine tails by chemical treatment and freeze thaw. Proceedings of the 46th Canadian Geotechnical Conference, April 4-7, 1993. Saskatoon, Saskatchewan, Canada. 392-400.

Slation, N. A., R. J. Norman, B. R. Wells, D. M. Miller, R. S. Helms, C.A. Beyrouty, and C. E. Welison, Jr, (Eds). 1994. Efficient use of fertilizer. 42-54. *In: Rice production handbook.* University of Arkansas Coop. Ext. Service, Little Rock.

Todd, R. M., and W. D. Kemper, 1972. Salt dispersion coefficients near an evaporating surface. Soil Sci. Soc. Amer. Proc. 36: 539-543.

Chapter – 5

Influence of Saline Processing Water on Plant Water Relations of Dogwood (*Cronus stolonifera.* Michx.) and Highlander Grass (*Elymus trachycaulus* subsp. *Trachycaulus*)

5.1. Introduction

Presence of salt in soil water affects plant water relations (Bolanos and Longstrength, 1984) primarily by decreasing osmotic potential of the soil water (Osmotic effect). Salt in soil water reduces the availability of water to plants by decreasing osmotic potential in soil matrix (Lamsal et al., 1999). The decrease in osmotic potential hinders water uptake by roots (Greenway and Munns, 1980), which reduces the transpiration rate (Katerji et al., 1996), and thereby reduces plant growth. The reduction in growth in response to salt is mainly caused by increasing the energy that must be spent on water uptake and making the biochemical adjustments (such as osmotic adjustment) necessary to survive under stress (Hamdy et al., 1993). High concentration of salt in soil water decreases the cell water potential in response to decreasing soil water potential and reduces protein hydration and enzyme activity (Kramer, 1986). Therefore, plants growing in the saline environment grow slowly and are therefore stunted.

There are other factors in addition to the decreased osmotic potential (osmotic effect) that affects plant growth under saline condition. These factors include toxicity effect and nutritional effect. Presence of high concentration of specific ions, such as SO_4^{2-}, Na^+, Cl^-, and Ca^{2+} (main ions of salt) in soil solution causes injury to plants growing in saline soil (Martin and Koebner, 1995; Shannon et al., 1994). Presence of salt in soil water increases the concentration of some ions, specifically sodium and chloride (Epestein and Rains, 1987; Szabolcs, 1989). This increases the ratio of these ions to other ions, which are already present in the soil, and cause deficiencies of nutrient elements present at much lower concentrations (Yahya, 1998; Micklebart and Marler, 1996).

Plants growing in saline condition reduce their cells osmotic potential in response to decreased cell water potential, and therefore maintain the turgor potential and growth. This adjustment in plants osmotic potential is called as osmotic adjustment and is one of the major drought and salt tolerance mechanisms (Nobel, 1996). The osmotic adjustment is mainly brought about by increasing solute concentration in cell sap (Binzel et al., 1988). Potassium is the major ion responsible for osmotic adjustment in many salt tolerant plants. At high salinity, levels of organic acid in the tissues increase, which results in the greater uptake of potassium (Bernstein, 1963).

These effects caused by salts in the soil can be expected to be present for plants exposed to the saline water released from the composite tailings. If salts from the CT water accumulate in the rooting zone, it may adversely affect plant growth. Accumulation of salt in the rooting zone may be reduced by separating CT water from the surface soil with a layer of tailings sand used as a capillary barrier. The effectiveness of the sand layer in preventing the adverse effect of saline CT water on plant growth depends on the thickness of the sand cap between CT water and surface soil, and on characteristics of plants. Dogwood has been shown to be a salt tolerant species (Renault et al., 1999) therefore is expected to perform well under saline conditions. Dogwood is a rapidly growing shrub well adapted to disturbed sites. It is also a native boreal species that is excellent at stabilizing soil (HBBT Ltd., 1989) and attracting wildlife (Robbins and Moen, 1975). Highlander grass is native to the Northern Alberta region. These two species were selected for this study.

The aim of this chapter is to study the effect of saline CT water on water relations of dogwood and highlander grass.

5.2. Materials and methods

The experimental set up is as described in chapter 3. Briefly, dogwood and highlander grass were grown in columns consisting of 65 cm of tailings sand capped by 30 cm of reclamation material (soil-peat mix) in a growth chamber. Constant CT water level (0, 30, 60 cm from soil/sand interface) was maintained throughout the experiment. Two watering rates (3mm and 6 mm per application) were used to simulate dry and wet conditions. A total of 12 treatments (2 plant species, 3 CT water levels, and 2 watering rates) were used. For dogwood, seedlings were transplanted into 9 randomly selected columns (3 seedlings/column) on 2nd November, 1999. Ten grams of the highlander grass seeds were evenly divided and sowed in the remaining 9 columns on 4th November, 1999. During the experiment, two drought periods were simulated to study the survival of plants under mild and severe drought conditions, by withholding irrigation water. The first drought period lasted for 16 days. The second, more severe drought period lasted for 66 days. After 66 days some of the plants started to die, therefore application of irrigation water was resumed. Plant performances before and during the drought periods, as well as the recovery after the drought periods were monitored. The analyses reported in this chapter include leaf water potential and osmotic potential, as these are important physiological indicators of plant response to saline and water stress conditions.

5.2.1. Water potential (Ψ_w) measurement

Plants total water potential was measured on five randomly selected, fully exposed mature leaves from each column by a pressure chamber (**PMS** Instrument Co. Corwallis, Oregon, USA). Measurements were done between 10 AM to noon, as timing plays a crucial role in the plant water potential measurement (Li, 2001). Each selected leaf was first wrapped with SARAN WRAP to prevent water loss during measurement. The leaf was then cut from the petiole with a razor blade, and put immediately to the pressure chamber for total water potential measurement.

5.2.2. Osmotic potential (Ψ_s) measurement

After total water potential measurement was completed, three leaves were cut and placed immediately in airtight plastic tubings and frozen in dry ice. Later these samples were thawed on a lab bench. Cell sap was extracted by forcing the plastic tubings through a roller and was used for osmotic potential measurement with a Vapour Pressure Osmometer (VAPRO, model # 5520, MANDEL Scientific Co. Ltd., Utah, USA). The osmometer was calibrated with the standard KCl solution of 100, 290, and 1000 µmol/kg. The results (osmolality) obtained were in µmol/kg, which was then converted into osmotic potential (MPa).

5.2.3. Statistical analysis

Statistical analyses of water potential and osmotic potential data was done by using the General Linear Model procedure of SAS (SAS Institute, 1990). The data used for the analysis were means of the three replicates for each treatment.

5.3. Results

5.3.1. In the early period

5.3.1.1. Water potential (Ψ_w)

The first water potential (Ψ_w) measurement on dogwood and highlander grass leaves was taken on 29th February 2000. In dogwood, Ψ_w increased in all the treatments after May, however, the difference in the Ψ_w with different CT water levels was not significant. At low irrigation, significant increase in Ψ_w was observed with decrease in CT water level depth. Highlander grass showed a similar trend.

No significant difference between the two plant species was recorded. Both dogwood and highlander grass showed significantly lower Ψ_w in the treatment where CT water level was at 0 cm than where it was at 60 cm (Table 5.1). In both plant species little fluctuation in Ψ_w with time within the same treatment was observed.

5.3.1.2. Osmotic potential (Ψ_s)

Leaf Ψ_s of both dogwood and highlander grass showed similar trend as did Ψ_w. Lower Ψ_s was recorded in CT water level at 0 cm and highest in CT water level at 60 cm. Ψ_s was recorded lower at low irrigation rate than at high irrigation rate (Table 5.2). By the end of July, Ψ_s decreased in all treatments.

5.3.1.3. Turgor potential (Ψ_p)

Significant increase in Ψ_p was recorded in all the treatments (Table 5.3). In the beginning of the measurement (February), dogwood showed Ψ_p close to 1 MPa in low irrigation and close to 0.5 MPa in high irrigation. Ψ_p of dogwood reached close to 1 MPa by July in all the treatments.

Highlander grass showed significantly lower Ψ_p than dogwood, however, it reached close to 0.5 MPa in all the cases by July. No significant difference was recorded in the Ψ_p of either of the plant species with the CT water level and/or irrigation.

5.3.2. During first short drought period

5.3.2.1. Water potential (Ψ_w)

Results of Ψ_w of dogwood and highlander grass during first drought period are shown in Figure 5.1. There was a significant interaction of the CT water levels and irrigation ($p = 0.0069$) on the Ψ_w of dogwood (Table 5.4). Under high irrigation rate, there is no significant difference in Ψ_w between the three depths of CT water levels. However, under low irrigation, CT water level at 30 cm and 60 cm showed significantly lower Ψ_w than treatment with CT water level at 0 cm. In treatments with CT water levels at 30 cm and 60 cm, Ψ_w reached -1.8 MPa. Maximum decrease in the Ψ_w was recorded in the treatment with low irrigation and 30 and 60 cm CT water levels. It reached from -0.5 MPa to -1.8 MPa, a decrease of 1.3 MPa in 16 days.

In highlander grass, there was no significant interaction of water level and irrigation

($p = 0.15$). Irrigation rate had no effect on Ψ_w ($p = 0.34$). However, water level had significant effect on the Ψ_w of highlander grass leaves ($p = 0.0005$). CT water level at 0 cm resulted in significantly lower Ψ_w than at 30 cm and 60 cm ($p = 0\ .006$ and 0.0002 respectively), however, 30 cm CT water level showed no significant difference from 60 cm ($p = 0.13$).

Highlander grass showed smaller decrease in Ψ_w than dogwood. Lowest decrease was observed in treatment with the water level at 60 cm where Ψ_w reached - 1.3 MPa from - 0.6 MPa, decrease of 0.7 MPa in 16 days. Under low irrigation, only treatment with CT water level at 60 cm showed a constant decrease in Ψ_w with days (Figure 5.1).

5.3.2.2. Osmotic Potential (Ψ_s)

Results of Ψ_s of dogwood and highlander grass are shown in Figure 5.2. Results of statistical analysis are shown in Table 5.4. There was no significant interaction of CT water level and irrigation rate on the Ψ_s of dogwood ($p = 0.07$). However, CT water levels and irrigation had significant effect ($p = 0.001$ and <0.0001 respectively). CT water level at 0 cm resulted in significantly higher Ψ_s than at 30 cm and 60 cm ($p = 0\ .0003$ and 0.009 respectively), however, 30 cm CT water level showed no significant difference from 60 cm ($p = 0.15$). Low irrigation rate resulted in significantly lower Ψ_s than high irrigation rate ($p < 0.0001$).

There was a significant interaction of CT water level and irrigation rate on the Ψ_s of highlander grass ($p = 0.03$). Maximum decrease in the Ψ_s was recorded in low irrigation and CT water level at 60 cm below the interface (-1.2 MPa to -1.8 MPa), whereas high irrigation showed the least decrease (from -1.15 MPa to - 1.25 MPa) (Figure 5.2). Dogwood resulted in significantly lower Ψ_s than highlander grass ($p = 0.008$).

5.3.3. During the second, longer drought period

5.3.3.1. Water Potential (Ψ_w)

Results of Ψ_w of dogwood and highlander grass during the second drought period are shown in figure 5.3. There was a significant interaction of CT water level and irrigation rate on the Ψ_w of dogwood ($p = 0.004$). Ψ_w recorded in treatment with CT water level at 0 cm was significantly higher than in treatments at CT water level at 30cm and 60 cm below the interface. There was no significant difference in the Ψ_w of dogwood growing on CT water level at 30 cm and at 60 cm below the interface. Low irrigation rate resulted in significantly lower Ψ_w than high irrigation rate ($P < 0.0001$).

Highlander grass also showed a significant interaction of CT water levels and irrigation rate on their Ψ_w ($p < 0.0001$). Low irrigation rate caused greater reduction in Ψ_w than high irrigation rate ($p = 0.01$).

5.3.3.2. Osmotic Potential (Ψ_s)

Results of Ψ_s of dogwood and highlander grass during the second longer drought period are shown in figure 5.4. There was a significant interaction between the irrigation rate and the CT water levels on the Ψ_s of dogwood ($p = 0.009$). Under high irrigation, treatment with CT water level at 0 cm showed the lowest Ψ_s and treatment with CT water level at 60 cm showed the highest Ψ_s. However, no significant difference was observed in the treatments with CT water level at 30 cm and 60 cm below the interface. Low irrigation caused in greater reduction in that high irrigation rate ($p < 0.0001$). Ψ_s started to decreases after day 15 in all the treatments.

There was a significant interaction of the irrigation rate and the CT water levels on the Ψ_s of highlander grass ($p = 0.03$). Under high irrigation, treatment with CT water level at 0 cm showed maximum decrease in the Ψ_s and treatment with CT water level at 30 cm below the soil/sand interface showed the highest increase over 66 days. All three water levels were found to be significantly different than each other. Under low irrigation, treatment with lowest CT water level recorded the lowest Ψ_s reading and the CT water level at the interface showed the maximum value. Ψ_s showed similar trend as Ψ_w.

There was a significant effect of water level and irrigation on the water potentials of both dogwood and highlander grass ($p < 0.0001$). However, there was no effect of interaction on Ψ_s ($p = 0.72$). CT water level at 0 cm showed significantly lower Ψ_w and Ψ_s than at 30 and 60 cm. High irrigation resulted in significantly higher Ψ_w and Ψ_s in both dogwood and highlander grass ($p < 0.0001$). Dogwood had significantly lower Ψ_s than highlander grass ($p < 0.0001$) whereas Ψ_w was measured significantly lower in highlander grass ($p < 0.0001$).

5.4. Discussion

5.4.1. Early period

In the beginning of the experiment, when plants were small, both Ψ_w and Ψ_s showed no significant difference with the CT water levels or irrigation (Table 5.1). However, with time, CT water level at 0 cm showed reduction in the Ψ_w and Ψ_s than at 30 cm and 60 cm. The reduction in the Ψ_w and Ψ_s of dogwood and highlander grass growing in treatment with CT water level at the interface might be due to higher concentration of salt present in the soil layer, as shown in Chapter 4 (Table 4.1 and 4.2). The reduction in Ψ_s is greater at low irrigation than at high irrigation, which is consistent with the fact that these treatments had higher EC values in the soil layer (Chapter 4). For example, the treatment with dogwood receiving low irrigation recorded high EC value of 6.4 dS/m in February 2000 (refer to Table 4.1) and Ψ_s of dogwood receiving same treatment was recorded to be as low as - 1.9 MPa in that month (Table 5.2). These results are consistent with the hypothesis that saline condition and lower irrigation induce water stress (lower $\Psi_{w)}$ in plants and that plants respond by osmotic adjustment. These results are in agreement with the findings of Renault et al. (1999), Morales et al. (1998), Katerji et al. (1997), and Devitt et al. (1993). Bernstein (1963) also reported a decrease in Ψ_s in bean leaf sap during the first 24 hours after the addition of salt. Salinity has been known to reduce the availability of water to plants by developing osmotic potential in soil matrix (Lamsal et al., 1999). Osmotic adjustment takes place in the first few days following a decrease in the Ψ_s of the medium.

5.4.2. Drought periods

Results from the first drought period showed a decrease in Ψ_w of both dogwood and highlander grass (Figure 5.1). At low irrigation, dogwood with 60 cm and 30 cm CT water level showed maximum decrease in Ψ_w in 16 days. However, at high irrigation, CT water level at 0 cm resulted in significantly lower Ψ_w than the other two water levels. The Ψ_w of dogwood was lowered in response to the absence of sufficient moisture at low irrigation and low CT water level. However, high CT water level seemed to meet the water demand by plants. For dogwood receiving low irrigation, soil moisture content at the onset of the drought period was lower and therefore a moisture deficit condition developed quickly during the drought period. Water requirement during the drought period was particularly met by CT water present close to the surface (0 cm treatment). The low moisture content also resulted in increase in salinity in the soil layer (Chapter 4). Treatment with CT water level at 0 cm provided moisture from the CT water which helped in keeping Ψ_w high. Ψ_s analysis showed similar results as Ψ_w. In both highlander grass and dogwood, low irrigation resulted in lower Ψ_s than in high irrigation. In either irrigation rate, CT water level at 0 cm resulted in highest Ψ_s, suggesting that in absence of any irrigation water or rainfall (under natural condition), CT water may be beneficial.

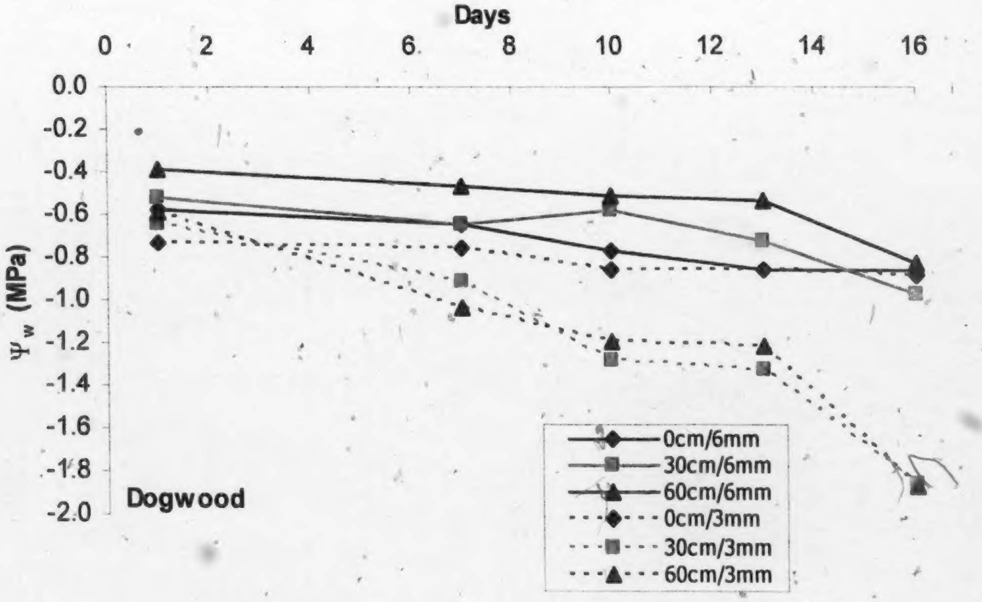
A second, longer drought period was used to monitor the survival of the two plant species under extreme drought conditions. Dogwood at low irrigation showed decrease in Ψ_w after day 9 until the end of the drought period, when it reached - 1.4 MPa and then increased to - 0.7 MPa upon the application of irrigation water and then remained almost constant until the end of the experiment. The recovery of Ψ_w – 0.7 MPa is comparable to those before the drought treatment. Under low irrigation, CT water level at 0 cm showed significantly higher Ψ_w. The increase in Ψ_w may be because when the CT water level was high, plants were getting moisture from the CT water whereas, when CT water level was at 30 cm and 60 cm depth, it is less available to the plants because few roots reach that depth. At high irrigation, there was less decrease in the Ψ_w regardless of depths of CT water levels, which might be due to the fact that high initial water content kept the moisture available for the plants and that low salt concentration in the soil profile (Chapter 4) allowed for more roots to reach lower depth to access CT water (Chapter 6). This is supported by the fact that CT water must be added frequently to maintain constant CT water level. However this has resulted in the accumulation of salts in surface soil. Another possible reason might be the soil compaction to a significant level (Table 5.5), which might have decreased the CT water level depths. The decrease in the capping thickness in treatment with highlander grass might have caused an irregular pattern in both Ψ_s and Ψ_w of highlander grass. Katerji et al. (1998), have also shown an irregular trend in the Ψ_w of broadbean leaf, because Ψ_w increased after each irrigation, which was followed by a decrease during the irrigation interval.

Low irrigation resulted in significantly lower Ψ_w and Ψ_s in both dogwood and highlander grass ($p < 0.0001$), which might be due to greater accumulation of salt and low available water in the soil layer (Chapter 4). The higher salinity increased the osmotic pressure of the soil solution (Greenway and Munns, 1980), which hinders the water uptake by roots. This restriction in water uptake caused lowering of Ψ_w in both the plant species. Salt concentration in soil solution has been found to be inversely related to the soil water content (Hillel, 1996). Decrease in soil water content increases the salt concentration in soil which causes reduction in the soil water potential as soil water content affects the solute concentration (Meiri and Poljakoff-Mayber, 1969, Katerji et al., 1998). The adverse effect of salinity increases with increasing time of exposure to salinity. Decrease in leaf water potential and leaf osmotic potential at higher salt content was also observed by Morales et al., 1998, van Hoorn et al., 1993, Huang and Redman, 1995). Morales et al. (1998) showed that *Argyranthemum coronopifolium* under saline condition showed decrease in Ψ_w and Ψ_s significantly. However Ψ_p was significantly higher in saline treatment plants. This increase in Ψ_p caused by salinity together with the significant decrease in Ψ_w and Ψ_s could be due to solute accumulation in leaf tissue (osmotic adjustment). Renault et al. (1999) also reported a decrease in Ψ_w of dogwood leaf at higher salinity. Lowering of Ψ_s was found to be in response to lowering of Ψ_w in order to maintain the turgidity of the plant cell. Results from this study are also in agreement with the findings of Morales et al. (1998), and Renault et al. (1999), suggesting that the salt tolerance mechanism by these plant species are due to decrease in osmotic potential (osmotic adjustment).

Results from the longer drought period also showed that, both dogwood and highlander grass were able to keep their Ψ_w and Ψ_s high till day 25 (Figure 5.3 and Figure 5.4), suggesting that they were performing well in absence of irrigation for more than three weeks. Results from the photosynthesis analysis (Chapter 6, Figure 6.2) also support this. The maximum duration of survival of the two plant species on saline CT water was recorded up to 66 days. After day 66, dogwood and highlander grass growing on the high CT water level and low irrigation and low CT water level and low irrigation started to die.

5.5. Conclusion

Based on the experimental observation, this study suggests that low irrigation and CT water level at 0 cm depth did seem to hinder the water uptake by plant roots, thereby reducing Ψ_w. Both dogwood and highlander grass seemed to tolerate salinity by lowering their Ψ_s through osmotic adjustment. However, in absence of irrigation water, CT water level at 0 cm depth provided enough moisture to maintain Ψ_w high. Results from the longer drought period indicate that both dogwood and highlander grass can tolerate the drought condition for the maximum of two months in the growth chamber. This has practical implication on the survival period of these plant species growing on the reclaimed CT under drought condition. However, this might not necessarily be true in the field, because in the field, climatic conditions like temperature and precipitation vary, while they were kept constant in this study. Nonetheless, this study provided a basic understanding about the water relation of the two plant species affected by the saline CT water. Based on the data provided in this chapter, its reasonable to conclude this that CT water level at 60 cm depth and high irrigation seemed to prevent the adverse effect of salt from the CT water on the Ψ_w and Ψ_s of dogwood and highlander grass.



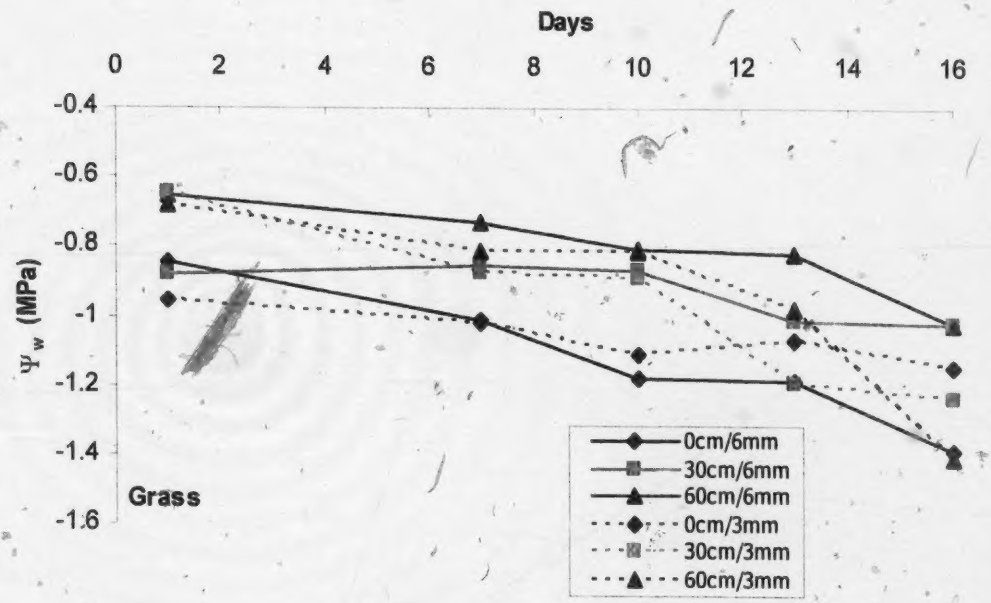
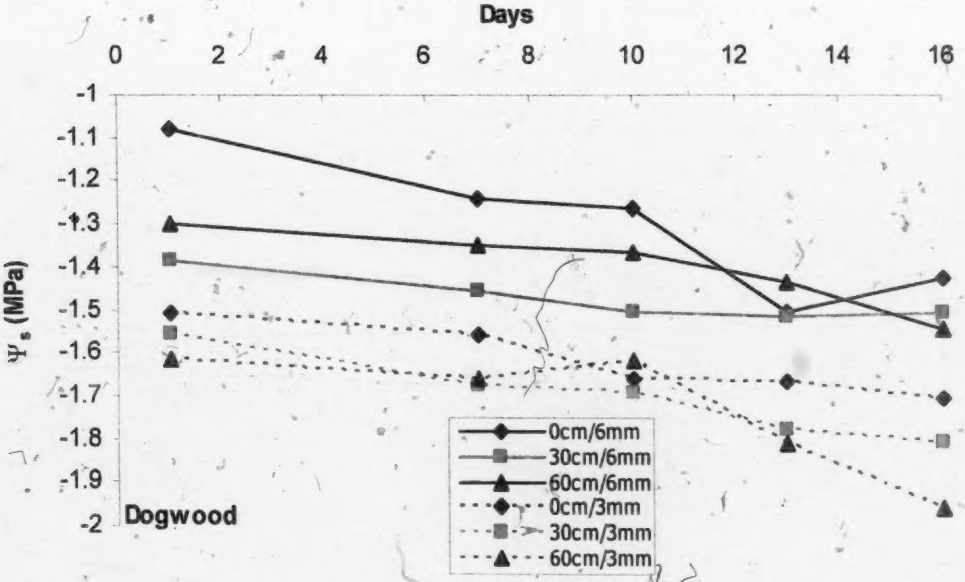


Figure 5.1. Water potential of dogwood and highlander grass during the first drought period. Solid line represents high irrigation and broken line represents low irrigation. Circle, square, and triangle are used to represent 0cm, 30 cm, and 60 cm CT water level depth respectively. S.E for dogwood is 0.1 and for grass is 0.06.



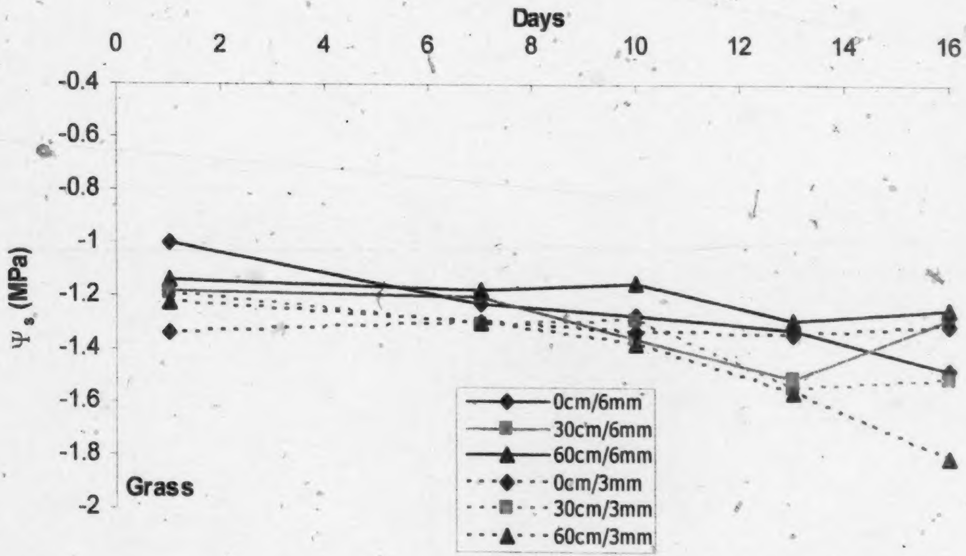
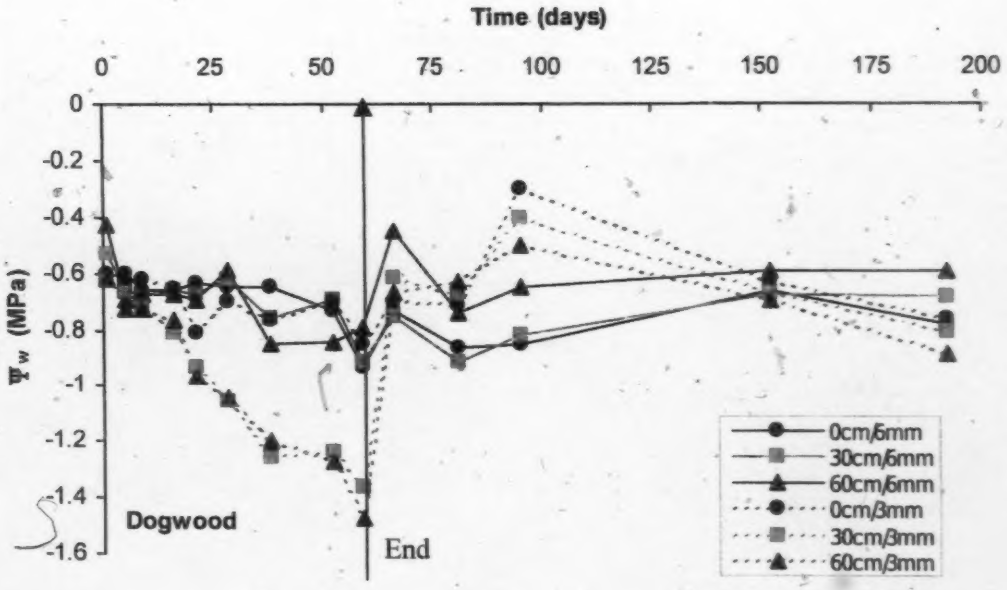


Figure 5.2. Osmotic potential (Ψ_s) of dogwood and highlander grass during the first drought period. Solid line represents high irrigation and broken line represents low irrigation. Circle, square, and triangle are used to represent 0 cm, 30 cm, and 60 cm CT water level depth respectively. S.E for dogwood is 0.04 and for grass is 0.05.



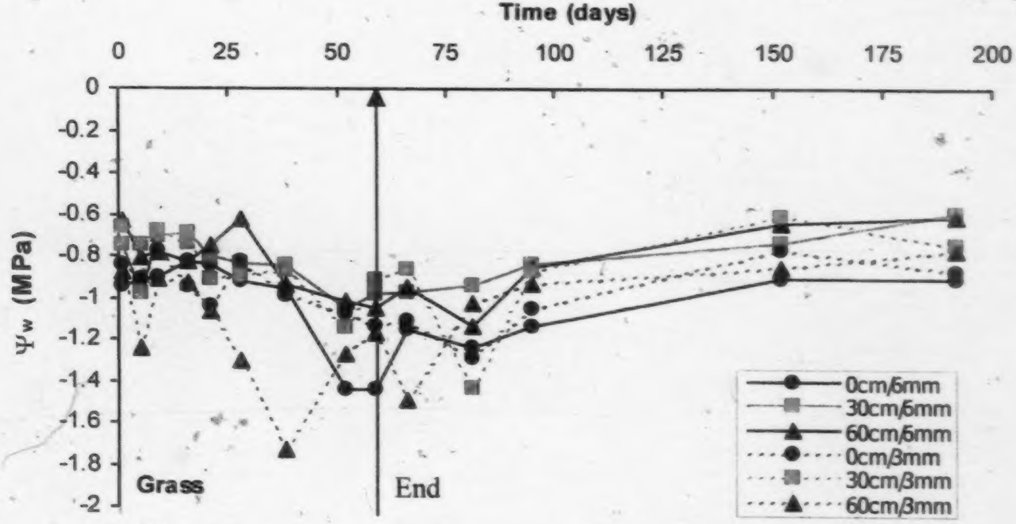
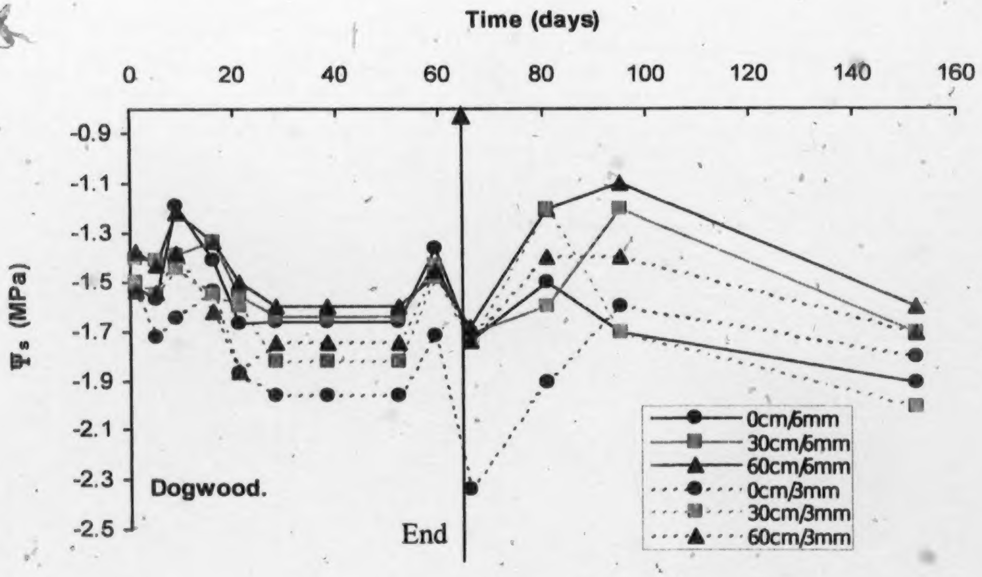


Figure 5.3. Water potential of dogwood and highlander grass during and after long drought period. End represents the end of the drought period. S.E for dogwood is 0.08 and for grass is 0.08.



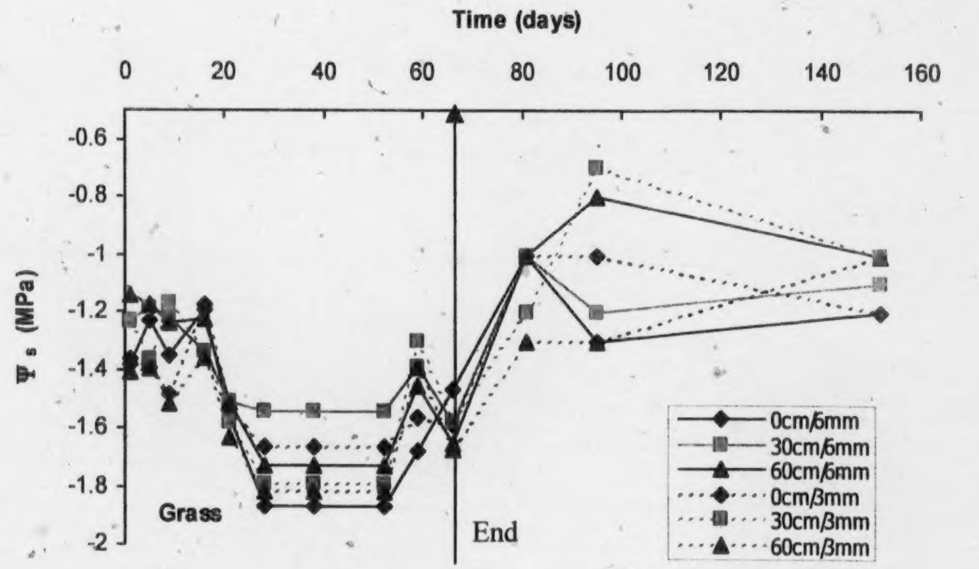


Figure 5.4. Osmotic potential (Ψ_s) of dogwood and highlander grass during and after long drought period. End represents the end of the drought period. S.E for dogwood is 0.05 and for grass is 0.06.

Table 5.1. Water potential of dogwood and highlander grass recorded in the early period of the experiment prior to the onset of short drought period. The numbers are averages of the three measurements.

Dogwood	Water potential (MPa) Month of the measurement taken				
Treatment	February	April	May	June	July
0cm/ 6mm	-1.2	-1.1	-1.1	-0.8	-0.8
30cm/ 6mm	-1.0	-1.1	-0.9	-0.7	-0.7
60cm/ 6mm	-1.0	-1.0	-1.1	-0.6	-0.6
0cm/ 3mm	-1.1	-1.3	-1.3	-1.0	-1.0
30cm/ 3mm	-0.9	-1.2	-1.2	-0.6	-0.6
60cm/ 3mm	-0.7	-1.0	-1.0	-0.6	-0.6

Grass	Water potential (MPa) Month of the measurement taken			
Treatment	February	April	May	July
0cm/ 6mm	-1.3	-1.3	-1.0	-1.0
30cm/ 6mm	-1.0	-1.0	-0.6	-0.9
60cm/ 6mm	-0.8	-0.8	-0.6	-0.8
0cm/ 3mm	-1.2	-1.2	-1.1	-1.1
30cm/ 3mm	-0.6	-1.0	-0.8	-0.9
60cm/ 3mm	-0.8	-0.9	-0.6	-0.9

Table 5.2. Osmotic potential of dogwood and highlander grass recorded in the early period of the experiment prior to the short drought period. The numbers are average of the three measurements.

Dogwood	Osmotic potential (MPa) Month of the measurement taken				
Treatment	February	April	May	June	July
0cm/ 6mm	-1.7	-1.8	-1.6	-1.4	-1.8
30cm/ 6mm	-1.6	-1.8	-1.6	-1.4	-1.7
60cm/ 6mm	-1.5	-1.8	-1.3	-1.3	-1.5
0cm/ 3mm	-1.9	-1.8	-1.6	-1.5	-2.0
30cm/ 3mm	-1.7	-1.7	-1.5	-1.4	-1.8
60cm/ 3mm	-1.6	-1.3	-1.4	-1.3	-1.8

Grass	Osmotic potential (MPa) Month of the measurement taken			
Treatment	February	April	May	July
0cm/ 6mm	-1.6	-1.2	-1.5	-1.4
30cm/ 6mm	-1.4	-1.1	-1.3	-1.3
60cm/ 6mm	-1.4	-1.0	-1.2	-1.2
0cm/ 3mm	-1.3	-1.6	-1.5	-1.6
30cm/ 3mm	-1.3	-1.4	-1.3	-1.3
60cm/ 3mm	-0.9	-1.2	-1.1	-1.4

Table 5.3. Turgor potential of dogwood and highlander grass recorded in the early period of the experiment prior to the short drought period. The numbers are the difference between the WP and the OP from Tables 5.1 and 5.2.

Dogwood	Turgor potential (MPa) Month of the measurement taken				
Treatment	February	April	May	June	July
0cm/ 6mm	0.5	0.7	0.5	0.6	1
30cm/ 6mm	0.6	0.7	0.7	0.7	1
60cm/ 6mm	0.5	0.8	0.2	0.7	0.9
0cm/ 3mm	0.8	0.5	0.3	0.5	1
30cm/ 3mm	0.8	0.5	0.3	0.6	1.2
60cm/ 3mm	0.9	0.3	0.4	0.5	1.2

Grass	Turgor potential (MPa) Month of the measurement taken			
Treatment	February	April	May	July
0cm/ 6mm	0.3	0.1	0.5	0.4
30cm/ 6mm	0.4	0.1	0.7	0.4
60cm/ 6mm	0.6	0.2	0.6	0.4
0cm/ 3mm	0.1	0.4	0.4	0.5
30cm/ 3mm	0.7	0.4	0.5	0.4
60cm/ 3mm	0.1	0.3	0.5	0.5

Table 5.4 ANOVA summary for WP and OP of dogwood and highlander grass during short drought period (drought period 1) and long drought period (drought period 2).

Effect Plant	Source	DF	Pr > F Drought Period 1	Pr > F Drought period 2
(Water Potential)				
Dogwood	Water level	2	0.1520	0.0067*
	Irrigation	1	<0.0001*	<0.0001*
	Water Level*Irrigation	2	0.0069*	0.0043*
Highlander grass	Water level	2	0.0005*	0.0003*
	Irrigation	1	0.3559	0.0098*
	Water Level*Irrigation	2	0.1436	<0.0001*
(Osmotic potential)				
Dogwood	Water level	2	0.001*	<0.0001*
	Irrigation	1	<0.0001*	<0.0001*
	Water Level*Irrigation	2	0.0718	0.0083*
Highlander grass	Water level	2	0.0628	0.0236*
	Irrigation	1	0.001*	0.0194*
	Water Level*Irrigation	2	0.029*	0.0322*

* significant at $\alpha = 0.05$

5.6. References

Bernstein, L., 1963. Osmotic adjustment of plants to saline media. II. Dynamic phase. Am. J. Bot. 50: 360-370.

Binzel, M., F. Hess, R. Brown, and P. Hassegawa, 1988. Intracellular compartmentalization of ions in adapted tobacco cells. Plant Physiol. 86: 607-614.

Bolanos, J.A., and D.J. Longstreth, 1984. Salinity effects on water potential components and bulk elastic modulus of *Alternanthera philoxeroides* (Mart.) Griseb. Plant physiol. 75: 281-284

Devitt, D.A., D.C. Bowman, and P.J. Schulte, 1993. Response of *Cynodon dactylon* to prolonged water deficits under saline conditions. Plant and Soil. 148: 239-251.

Epstein, E., and D.W. Rains, 1987. Advances in salt tolerance. Plant and Soil. 99: 17-29.

Greenway, H., and R. Munns, 1980. Mechanisms of salt tolerance in nonhalophytes. Ann. Rev. Plant. Physiol. 31: 149-190.

Hamdey A., S. Abdel-Dayem, and M. Abu_Zeid, 1993. Saline water management for optimum crop production.

H.B.B.T Limited, 1989. Manual of plant species suitability for reclamation in Alberta. 2nd ed. Rep no. RRTAC89-4. Alberta Land Conservation and Reclamation Council, Edmonton, Alberta. Canada.

Hayward, H.E., and W.B. Spurr, 1994. Effects of isosmotic concentrations of inorganic and organic substrates on entry of water into corn roots. Bot. Gaz. 106:131-139.

Hillel, D., 1996. Environmental Soil Physics. Academic Press, San Diego.

Huang, J., and R.E. Redmann, 1995. Salt tolerance of *Hordeum* and *Brassica* species during germination and early seedling growth. Can. J. Plant Sci. 75: 815-819.

Janzen, H.H., and C. Chang, 1987. Cation nutrition of barley as influenced by soil solution composition in a saline soil. Can. J. Soil Sci. 67: 619-629.

Katerji, N., J.W. van Hoorn, A. Hamdy, F. Karam, and M. Mastrorilli, 1996. Effect of salinity on water stress, growth, and yield of maize and sunflower. Agric. Water Manag.30: 237-249.

Katerji, N., J.W. van Hoorn, A. Hamdy, and M. Mastrorilli, 1998. Responses of tomatoes, a crop of indeterminate growth, to soil salinity. Agric. Water Manag. 38: 59-68.

Katerji, N., J.W. van Hoorn, A. Hamdy, M. Mastrorilli, and E. Mou Karzel, 1997. Osmotic adjustment of sugar beet in response to soil salinity and its influence on stomatal conductance, growth and yield. Agric. Water Manag. 34: 57-69

Kramer, P. J., 1983. Water relations of plants. Academic Press, New York.

Lamsal, K., N. P. Guna, and M. Saeed, 1999. Model for assessing impact of salinity on soil water availability and crop yield. Agric. Water Manag. 41: 57-70.

Li, X., 2001. Alberta Research Council, Edmonton, Alberta. Personal communication.

Martin, P. K., and R. M. K. Koebner, 1995. Sodium and chloride ions contribute synergistically to salt toxicity in wheat. Biol. Plant. 37: 265-271.

Meiri, A., and A. Poljakoff-Mayber, 1969. Effect of various salinity regimes on growth, leaf expansion and transpiration rate of bean plants. Soil Sci. 109: 26-34.

Mickelbart, M. V., and T. E. Marler, 1996. Root-zone sodium chloride influences photosynthesis, water relations, and mineral content of sapodilla foliage. Hort. Sci. 31: 230-233.

Morales, M. A., M. J. Sanchez-Blanco, E. Olmos, A. Torrecillas, and J. J. Alarcon, 1998. Changes in growth, leaf water relations and cell ultrastructure in *Argyranthemum coronopifolium* plants under saline conditions. J. Plant Physiol. 153: 174-180

Nobel, P. S., 1996. Physiochemical and Environmental Plant Physiology. Academic Press, San Diego, California.

Renault, S., E. Paton, G. Nilsson, J. J. Zwiazek, and M. D. MacKinnon, 1999. Responses of boreal plants to high salinity oil sands tailings water. J. Environ. Qual. 28: 1957-1962.

Robbins, C.T., and A. N. Moen, 1975. Composition and digestibility of several decidous browses in the northeast. J. Wild. Manag. 39: 337-341.

SAS Institute Inc., 1990. SAS users guide: Statistics. SAS Institute Inc., Cary, N.C.

Shannon, M. C., C. M. Grieve, and L. E. Francois, 1994. Whole-plant response to salinity. *In*: R. E. Wilkinson (ed.). *Plant environment interactions*. Marcell Dekker, New York.

Van Hoorn, J.W., N. Katerji, A. Hamdy, and M. Mastrorilli, 1993. Effect of saline water on soil salinity and on water stress, growth, and yield of wheat and potatoes. Agric. Water Manag. 23: 247-265.

Yahya, A., 1998. Salinity effects on growth and on uptake and distribution of sodium and some essential mineral nutrients in sesame. J. Plant Nut. 21: 1439-1451.

Chapter - 6

Impact of Composite Tailings Water on Photosynthesis and Growth of Dogwood (*Cronus stolonifera*. Michx.) And Highlander grass (*Elymus trachycaulus subsp. Trachycaulus*)

6.1. Introduction

The surface oil mining operations in Northern Alberta produce large volume of fine tailings. Natural consolidation of the fine tailings, even after hundreds of years, is not sufficient to make them suitable for terrestrial reclamation (Mikula et al., 1996a). One of the technologies developed to reduce the volume of fine tailings is to combine tailings sand, fine tailings and gypsum to produce composite tailings (CT) (Sego et al., 1993), which after self-weight consolidation, could be reclaimed. Composite tailings is relatively saline with sodium and chloride being derived from the oil sand, and sulfate comes from the gypsum, which was added in the production of CT (MacKinnon et al., 2000).

Reclamation of Composite Tailings for re-vegetation needs to deal with the effect of saline CT water (released after self-weight consolidation of CT) on the growth and development of plants. The high concentration of salts, in particular the sodium and sulfate, in the CT water requires attention on the choice and performance of reclamation species. Earlier studies showed that dogwood is relatively salt tolerant species among other boreal plant species, which are native to the Fort McMurray region (Renault et al, 1998,1999). And also dogwood is a rapidly growing shrub that grows well on disturbed sites. It is also a native boreal species that is excellent at stabilizing soil (H.H.B.T., 1989), and attracting wildlife (Robbins and Moen, 1975). Highlander grass is a native species that could be used for large-scale reclamation with reliable seed supply. However, it is not clear how this species will perform.

Presence of salt in soil water causes reduction in plant growth by reducing the availability of soil water (Al- Khafaf et al., 1990; Stewart et al., 1977), by causing toxic concentration of specific ions (Boursier and Lauchli, 1990) and by reducing micronutrient availability (Janzen and Chang, 1987). Accumulation of salt in the rooting zone decreases osmotic potentials of the soil solution, which ultimately reduces plant water uptake (Hayward and Spurr, 1994). Toxicity of ions causes injury to the plant tissues (Greenway and Munns, 1980). Nutrient imbalance can be caused by inhibition or promotion of the uptake of nutrient elements under saline conditions (Alam et al., 1994) and by the relatively high pH of the CT water. In addition to Na^+, Cl^-, and SO_4^{2-}, other components of CT water that may affect plant growth include B, Fl, Al, and Sr (Renault et al., 2001). Recent evidence suggests that the exposure of roots to the salinity may alter hormonal concentration in plant tissues (Azallag, 1997; Cheeseman, 1998) and also alter uptake of essential nutrients (Alam, 1994).

Salinity also affects photosynthesis. Photosynthesis is a major process involved in the determination of growth, dry weight production and yield of plants. The relationship between the sensitivity of photosynthesis and salinity is well documented (Downton, 1977; Seeman and Critchley, 1885; Walker et al., 1993; Khan et al., 1994; Awada et al., 1995; Marler and Zozor, 1996 and Mickelbart and Marler, 1996). Presence of salt in the soil solution decreases photosynthetic rate and hence growth of the plant by reducing the stomatal conductance and the entry of CO_2 to the chloroplast (Brugnoli and Lauteri, 1991; Downton et al, 1985,). In addition, salinity causes reduction in leaf area, which leads to the reduction in the light interception and therefore reduces the rate of growth (Greenway and Munns, 1980; Marcelis and Van Hooijdonk, 1999; Pearcy and Ustin, 1984; Rozema, 1991).

Root growth is affected under saline condition. However, studies have shown that root growth is generally less affected by salinity than shoot growth (Bernstein and Hayward, 1958) and hence the shoot to root ratio decreases (Meiri and Poljakoff-Mayber, 1969). Root density, distribution and root length are all adversely affected by salinity because of the decreased soil water potential (Bresler and Hoffman, 1986; Newman et al., 1994; Passioura, 1988).

This chapter focuses on the effect of saline CT water on photosynthesis and growth of dogwood and highlander grass.

6.2. Materials and methods

The experimental set up and treatments are as described in chapter 3. Dogwood and highlander grass were grown in 9 randomly selected columns each. Each column was filled with the tailings sand up to 65 cm capped with the top 30 cm of reclamation material (represented by soil in the results and discussion of this chapter for the simplicity sake). Two irrigation rates of 3mm/application and 6mm/application were applied to simulate dry and wet condition respectively. The experiment was run under two drought periods by withholding the irrigation water. The first shorter drought period was run for 16 days. The longer, more severe drought period was run for 66 days. The duration of the first drought period was based on choice, however, that of second drought period was on the plant's performance (some of the plants started to die by day 66). Analyses conducted for this chapter include rate of photosynthesis, leaf area, shoot dry weight, root dry weight, root volume, and root length.

6.2.1. Photosynthesis rate measurements

Rate of photosynthesis was measured on 5 randomly selected leaves from each column. The leaves were selected on the basis of maturity and position in the plant. All the leaves selected were fully mature but not old and facing toward the light. The analysis was done between 11 am to 1 pm by a portable photosynthesis analyzer (model # 6400, LI-COR Inc. Nebrasca, USA). For dogwood, a single leaf was clamped in the leaf chamber, which was 6 cm^2 in area and the photosynthesis rate was taken. For highlander grass, leaves length and width were measured before putting the particular leaf in the chamber and then rate of photosynthesis was converted to per leaf area basis.

6.2.2. Leaf Area

Plants were cut during and at the end of the experiment. Subsamples of leaves were used for leaf area measurement by a leaf area meter (Model 3100, LI-COR Inc., Nebraska, USA). Leaf area / dry weight of the sub-samples were used to calculate total leaf area.

6.2.3. Shoot dry weight production

Highlander grass and dogwood were cut 7 and 4 times respectively in the whole experimentation period. Dogwoods were cut when they grew to an extent of overlapping the other plant because of the space limitation and to avoid loss of leaves due to senescence at maturity. Highlander grass was harvested when they reached the full maturity. Highlander grass was kept in the oven at 65°C for 48 hours and the dry mass was taken. For dogwood, leaves and stems were kept separately. Leaves were kept at 65°C for 72 hours and stems were kept at the same temperature for one week, and dry mass was recorded.

6.2.4. Root Analysis

At the end of the experiment samples of 10 cm x 10cm x 10cm were collected from the surface soil layer. From the second (30 cm below the interface) and third depth (60 cm below the interface), core samples were taken. All the samples were collected in Ziplock bags and stored in a cold room (4°C). Roots were washed by hand with cold running water. Cleaned roots were stored in 90% ethenol in a cold room (4°C) until the root lengths and root volumes were analyzed. After all the measurements were done, root dry weight was taken on the same samples.

For root dry mass, washed roots were kept in the oven at 65°C for 24 hours. Dry mass was recorded. Root volume was measured by the water displacement method. Water was filled in a measuring cylinder up to the top and then roots (blotted dry with tissue paper) were put carefully in that cylinder. Water displaced by roots was collected. The displaced amount of water was measured in a measuring cylinder and the volume was recorded in ml. Root length was measured by image analysis by Win RHIZO 2001A and a HP scanner. Cleaned roots were blotted dry with tissue paper and widely spread in a dish (14 cm length and 8.8 cm width), containing water. Roots were carefully floated apart with the help of a needle to minimize the overlapping. These roots were then scanned by the HP scanner, and the image was analyzed for the root length.

6.2.5. Statistical analysis

Statistical analysis was done using General Linear Model procedure of SAS (SAS Institute, 1990). Means were compared using the Least Significant Difference at 95% confidence level.

6.3. Results

6.3.1. Photosynthesis (Pn)

6.3.1.1. First shorter dry period

Results of photosynthesis of dogwood and highlander grass during the short drought period are shown in Figure 6.1. CT water level and irrigation rate had no significant effect on photosynthetic rate of dogwood (Table 6.1). Low irrigation resulted in greater reduction in Pn than high irrigation, however the difference was statistically not significant. There was a decrease in the photosynthetic rate of dogwood with time ($p = 0.002$).

Rate of photosynthesis of highlander grass was not affected significantly by either CT water level or the irrigation rate (Table 6.1). There was no effect of time on Pn ($p = 0.5$). However, treatment with CT water level at 0 cm and high irrigation appeared to show decrease in Pn (Figure 6.1) with time.

6.3.1.2. Second longer drought period

Results of photosynthesis of dogwood and highlander grass during the long drought period are shown in Figure 6.2. In dogwood, Pn was significantly affected by CT water levels ($p = 0.02$). CT water level at 60 cm did cause greater reduction in Pn than at 30 cm and 0 cm. However, the difference was evident only after day 25 (Figure 6.2). Irrigation rate had no effect on Pn. Reduction in Pn was found to be due to time of exposure to drought. Rate of photosynthesis increased in all case after the application of irrigation water (after day 66, Figure 6.3).

In highlander grass, the decrease in Pn was caused by time of exposure to drought. There was no significant effect of CT water level or the irrigation rate on the Pn (Table 6.1). Rate of photosynthesis increased in all case after the application of irrigation water (after day 66, Figure 6.3).

6.3.2. Leaf area

Under high irrigation, leaf area of dogwood was significantly reduced by the CT water level ($p = 0.04$). CT water level at 0 cm resulted in greater reduction of leaf area than CT water level at 30 cm and 60 cm (Figure 6.3). Under low irrigation CT water level did not cause any significant difference in the leaf area. There was no significant effect of irrigation on leaf area of dogwood.

Leaf area of highlander grass was significantly affected by the CT water level and the irrigation rate ($p =0.0001$). High irrigation resulted in greater leaf area than low irrigation. Leaf area was also reduced by the decrease in the CT water level under high irrigation (Figure 6.3). However, at low irrigation, CT water level at 30 cm below the soil/sand interface resulted in greater leaf area than at the other two CT water levels.

6.3.3. Shoot dry weight production

Dogwood showed a significant interaction between the CT water level and irrigation on shoot dry weight production ($p = 0.007$). Within low irrigation, there was no significant effect of the CT water table on the dry weight of dogwood, whereas, there was a significant increase in the dry weight with the decrease in the CT water depth under high irrigation (Figure 6.4). CT water level at 0 cm resulted in significantly less dry weight production than CT water level at 30 cm and 60 cm ($p = 0.44$ and 0.005 respectively). However shoot dry weight production of dogwood at CT water level of 30 cm was not significantly different than that of 60 cm below the soil/sand interface (p = 0.2851). Irrigation had significant effect on the dry weight production of dogwood. Low irrigation resulted in less dry weight than high irrigation (p = 0.04). Shoot dry weight partition in stem and leaf of dogwood was found to be approximately equal in all the treatments (Figure 6.5). Dogwood also showed a good co-relation between the amounts of salt accumulated in the profile (from Chapter 4) and the dry weight production ($R^2 = 0.76$), whereas highlander grass showed no such relationship ($R^2 = 0.014$) (Figure 6.6).

Irrigation rate and CT water level had no significant influence on dry weight production of highlander grass (p = 0.41).

6.3.4. Root Dry Weight

There was no significant interaction between the CT water levels and irrigation rate on the root dry weight production of dogwood (p = 0.12). CT water level and irrigation alone affected the root dry weight of dogwood, however, the differences were statistically not significant (Table 6.1). High irrigation and low CT water level resulted in more root dry weight than CT water level at the soil/sand interface and 30 cm below the interface (Figure 6.7). Under high irrigation, root dry weight of dogwood increased with the decrease in the depth of CT water level. Under low irrigation, dogwood showed less root dry mass at high CT water level than at CT water level below 30 cm from the interface and 60 cm from the interface (Figure 6.7).

There was no significant interaction between the CT water levels and irrigation rate on the root dry weight production of grass (p = 0.75). However, root dry weight of highlander grass was significantly affected by irrigation rate (p = 0.03). Low irrigation resulted in significantly higher dry weight than high irrigation (p = 0.03). Root dry weight of highlander grass was not affected by the different CT water levels.

Shoot: root ratio of dogwood was reduced with lowering of the CT water level under low irrigation. Lowest shoot: root ratio was recorded in treatment with CT water level at 60 cm under both high irrigation and low irrigation (Table 6.3).

In highlander grass, shoot: root ratio decreased with the decrease in the CT water level irrespective of the irrigation rate. Shoot: root ratio was higher under high irrigation (Table 6.3).

6.3.5. Root Length

There was no interaction between the CT water level and the irrigation rate on root length of dogwood. Irrigation rate had no significant effect. However, root length was significantly affected by CT water levels (p=0.004). Under high irrigation, root length of dogwood increased significantly with the decrease in the CT water level. Under low irrigation, shortest root was recorded in the treatment with the CT water level at 0 cm (Figure 6.8). Roots were also found at 30 cm and 60 cm below the soil/sand interface (Figure 6.9). For dogwood, the greatest root length at this depth, were found where the CT water table was at 60 cm below the soil/sand interface. Some roots were also found in the tailings sand saturated with CT water under low irrigation.

Root length of highlander grass was not affected significantly by the CT water level and irrigation. Under high irrigation, grass growing on the CT water level at 30 cm below the interface had the greatest root length and at CT water level at 60 cm below the interface had the shortest root length. Under low irrigation, shortest root was recorded in the treatment with the CT water level at 30 cm (Figure 6.8).

6.3.6. Root distribution

6.3.6.1. Treatment with CT water level at 0 cm

In treatment with CT water level at 0 cm, most of the dogwood roots were found in the surface soil. High irrigation resulted in greater root length than low irrigation (Figure 6.9). Under low irrigation, some roots were also found in the 30 to 60 cm depth. No roots were found from 60 to 90 cm depth.

In treatment with CT water level at 0 cm, most of the highlander grass roots were also found in the surface soil as that of dogwood. However, in highlander grass, low irrigation resulted in greater root length than high irrigation (Figure 6.9). Under low irrigation, some roots were also found in the 30 to 60 cm depth, and 60 to 90 cm depth. Under high irrigation, some roots were also found in 30 - 60 cm below soil surface.

6.3.6.2. Treatment with CT water level at 30 cm

In treatment with CT water level at 30 cm, most of the dogwood roots were found in the surface soil. Low irrigation resulted in greater root length than high irrigation (Figure 6.10). Under high irrigation, some roots were also found in the 30 to 60 cm depth. No roots were found in 60 - 90 cm depth. Under low irrigation no roots were found below the surface soil.

In treatment with CT water level at 30 cm, most of the highlander grass roots were also found in the surface soil. Low irrigation resulted in significantly greater root length than high irrigation (Figure 6.10). Under high irrigation, some roots were also found in the 30 to 60 cm depth, and 60 to 90 cm depth. Under low irrigation, some roots were also found in 30 to 60 cm depth.

6.3.6.3. Treatment with CT water level at 60 cm

In treatment with CT water level at 60 cm, most of the dogwood roots were found in the surface soil. Under high irrigation, roots were found in all the three depths. However, under low irrigation, some roots were found in the 30 to 60 cm depth only. At all three depths, high irrigation resulted in greater root length than low irrigation (Figure 6.11).

In treatment with CT water level at 60 cm, most of the highlander grass roots were also found in the surface soil. Under low irrigation, roots were found in all the three depths. However, under high irrigation, some roots were found in 30 to 60 cm depth only. Low irrigation resulted in greater root length than high irrigation (Figure 6.11).

6.3.7. Root Volume

In dogwood, there was a significant interaction between the CT water level and irrigation rate on root volume ($p = 0.034$). CT water level affected root volume significantly ($p = 0.02$). Irrigation rate had no effect. Under high irrigation, CT water level at 60 cm resulted in highest root volume than at CT water level at 0 cm and 30 cm. CT water level at 0 cm resulted in minimum root volume. Under low irrigation, treatment with CT water level at 30 cm resulted in maximum root volume (Figure 6.12), however, the difference with the water level was not statistically significant.

In highlander grass, there was no significant interaction between the CT water level and irrigation rate on root volume ($p = 0.89$). Root volume was significantly affected by the CT water level ($p = 0.02$). Root volume in treatment with CT water level at 0 cm was significantly lower than at 30 cm ($p = 0.03$) and 30 cm was significantly different that at 60 cm depth ($p = 0.009$). Irrigation had no significant effect on the root volume of highlander grass.

6.4. Discussion

6.4.1. Photosynthesis

Rate of photosynthesis measured during the first and the second drought period showed no significant influence from CT water level and irrigation rate on either of the plant species (Table 6.2). The decrease in the rate of photosynthesis was only due to time of the exposure to the drought (caused by the longer drought period); however, in the longer drought period the effect was delayed until day 25 (Figure 6.2). The delayed response of the photosynthetic rate, in both plant species suggests that they can tolerate the drought for few weeks without having any adverse effect on their photosynthetic rate, The delay in reduction in Pn might be due to the gradual depletion of available water in the soil during the drought period when plants increasingly rely on CT water for survival. Photosynthetic activity, like growth is a turgor dependent process, which is affected by the water stress condition. Similar delayed response was observed in the water potential and osmotic potential measurement (Chapter 5) of dogwood and highlander grass, which suggests that reduction in photosynthetic rate, was related to reduction in the plant water potential. Water potential and osmotic potential of dogwood and highlander grass started to decrease only after day 25 (Chapter 5, Figure 5.3 and Figure 5.4). The decrease in the photosynthetic rate over time may be due to the accumulation of salt and development of water stress with time during the drought period. The increase in the concentration of salt (Chapter 4) in the soil profile caused reduction in the osmotic potential of the soil solution (Lamsal et al., 1999) restricting water uptake by the plant roots (Hayward and Spurr, 1994), and thereby reducing plant water potential. Leaf osmotic potential reduced in response to decrease in plant water potential (osmotic adjustment) (Chapter 5). Accumulation of salt increased during the longer drought period due to the unavailability of water, which might have caused in the partial closure of the stomata in order to reduce water loss and hence stomatal conductance was reduced. The reduction in stomatal conductance might be the cause behind reduction of photosynthetic rate, as shown by Ullah et al. (1993), and Amor et al. (2000). Result of photosynthesis data from this study is in agreement with Renault et al. (1998), who reported reduction in photosynthesis in dogwood growing on 100% CT water. Awada et al. (1995) have also found that stomata often partially closed in plants exposed to salinity, even when they have fully adjusted to the internal osmotic pressure and the turgor is high.

Another possible mechanism by which photosynthesis is reduced is due to reduction in leaf area caused by increased salinity as suggested by many authors (Greenway and Munns, 1980; Percy and Ustin, 1984; Rozema, 1991; Marcelis and VanHooijdonk, 1999). They suggested that reduction in the rate of photosynthesis at increased salinity was mainly due to reduction in leaf area, which caused reduction in light interception. Leaf area of dogwood did not show any significant reduction due to either CT water level or irrigation rate, which suggests that reduction in photosynthesis might be primarily due to reduced stomatal conductance as shown by Brugnoli and Lauteri (1991). However, leaf area of dogwood might be misleading because dogwood was pruned from the top only, except at the end of the experiment (Chapter 3). Leaf area of highlander grass was significantly affected by the CT water level and irrigation rate. However, Pn was not affected by either CT water level or the irrigation rate, suggesting that reduction in total Pn for highlander grass was mainly due to reduction in leaf area.

6.4.2. Growth

Shoot dry weight of dogwood was significantly affected by the CT water levels and the irrigation rate. Shoot dry weight of dogwood growing on CT water level at 0 cm and under high irrigation was lowest of all other treatments (Figure 6.4). The reduction in shoot dry weight might be due to water logging condition and salt caused by the high CT water level, which affected the root growth (Kramer and Kozlowoski, 1997). The reduction in shoot dry weight might also be due to toxicity effect caused by naphthanic acid present in CT water (Renault et al., 1999). Naphthanic acids have been shown to be toxic to many aquatic organisms, but their effects on plants have not been thoroughly studied (CONARD, 1998). However, naphthanic acids have surfactant properties (FTFC, 1995) and may affect the uptake of essential nutrients by plants (Devine st al., 1993). Another possible reason might be the high pH of CT water (Table 4.1), which might have caused nutrient deficiency (Noggle and Fritz, 1983). Leaf necrosis, a typical nutrient deficiency symptom was observed in treatment with high CT water level and low irrigation. Necrosis was more severe during longer drought period. Low irrigation resulted in significantly lower shoot dry weight.

Shoot dry weight of highlander grass was not affected either by the CT water level or the irrigation rates (Table 6.2), suggesting that roots of highlander grass were able to get moisture during the drought period because of their greater root system. Root length analysis supports the argument, which has shown longer root growth deeper in the soil profile. Results from the EC analysis and salt concentration in the soil profile have shown the accumulation of salt in the soil profile (Chapter 4). However, dry weight was not affected, suggesting that highlander grass was able to tolerate higher salt concentration. Correlation analysis between the shoot dry weight production and the salt accumulation in the soil profile also supports that shoot dry mater was not affected by the salt concentration (Figure 6.6). One of the possible salt tolerance mechanisms, which are supported by the data from this study, is that osmotic adjustment by lowering the osmotic potential under water stress condition might be sufficient to maintain the turgor potential and therefore, growth was unaffected. Many authors have reported the salt tolerance level of Bermuda grass (also a C_4 grass as highlander grass) under drought period and found that species to be highly salt and drought tolerant (Devitt et al., 1993; Ackerson and Younger, 1975; Marcum and Murdoch, 1990). Root dry weight of highlander grass was significantly affected by the irrigation rate; however, shoot dry weight was not, suggesting highlander grass is a drought resistant species as well.

Root dry weight of dogwood was not affected by either the CT water level or the irrigation rates, suggesting that root growth was not affected by the water status of the soil or higher salt concentration in the soil profile. However, root length and root volume was significantly affected by the CT water level (Table 6.2). One possible reason might be the toxic effect caused by sodium and sulfate ions on the roots. However, this toxic effect is not visible in the shoots, suggesting that dogwood root did not absorb these ions. However how the dogwood and highlander grass responded to the toxic effect needs further investigation. Renault et al. (1998) reported that CT water tolerance in dogwood might be due to salt exclusion by roots.

Many authors have shown reduction in shoot: root ratio (on dry weight basis) under saline condition, indicating shoots are affected more severely than roots (Meiri and Poljakoff-Mayber, 1999; Mass and Hoffman, 1977; Renault et al., 2001).

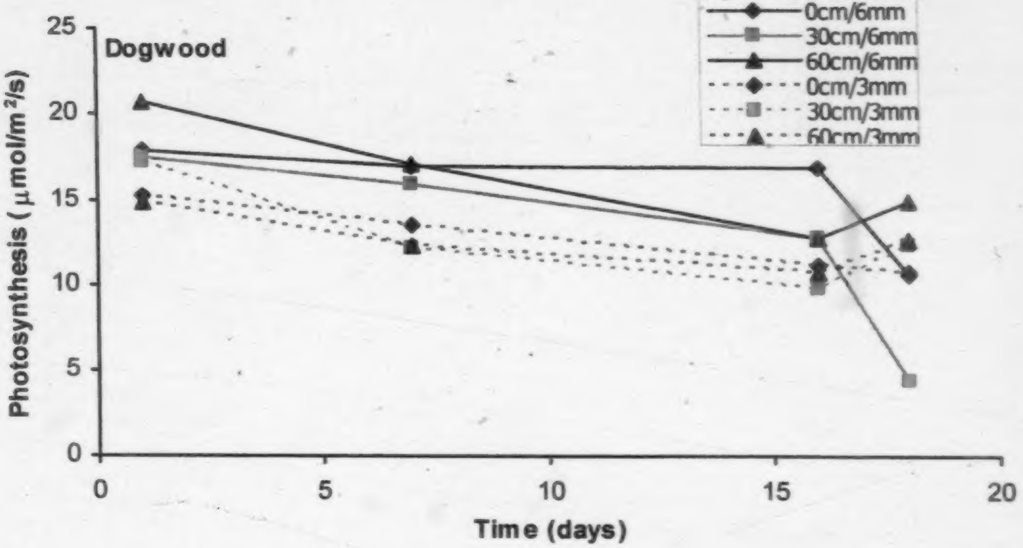
6.4.3. Root length distribution

In highlander grass, low irrigation resulted in greatest root length (Figure 6.9 to 6.11). Growth of root is inversely related to the amount of water present in soil. This follows the demand and supply rule. If demand for water by the plants is high (at high transpiration rate), roots will grow more in all the direction in order to meet the demand (if water is not available in the close vicinity). This water demand by the plants will result in more root growth but might also lead to reduction in shoot growth as more energy is invested towards root growth, causing shoot: root to decrease. Many authors have found a decrease in shoot: root under saline condition (Ackerson and Younger, 1975; Meiri and Poljakoff-Mayber, 1969). Renault et al. (2001) reported that shoot growth of dogwood was inhibited by salinity more than that of the roots resulting in the reduced shoot: root. Result from this study is in agreement with them.

6.5. Conclusion

The decrease in the rate of photosynthesis during the drought periods was mainly due to time of exposure to the drought as salt and water stress develop, which was caused by the reduction in the water potential and osmotic potential. The decrease in Pn was delayed for 25 days. However, The maximum duration of drought tolerance might be an overestimation for the field condition because of the fact that the results are from the growth chamber condition, where environmental variables were kept constant. Variation in the environmental condition such as temperature, precipitation will have great impact on the duration of the drought tolerance.

Based on the data from the shoot dry weight of the two plant species and the accumulation of salt in the soil profile at the end of the experiment (Chapter 3), it can be concluded that highlander grass can tolerate higher concentration of salt than dogwood. Correlation between salt concentration and the shoot dry weight of the two species also supports that grass is more salt tolerance than dogwood.



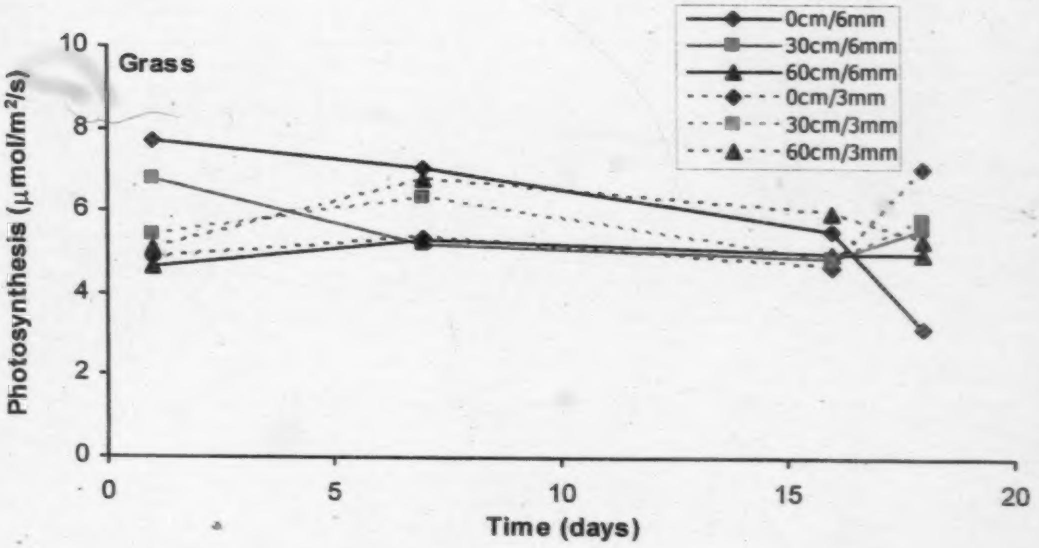
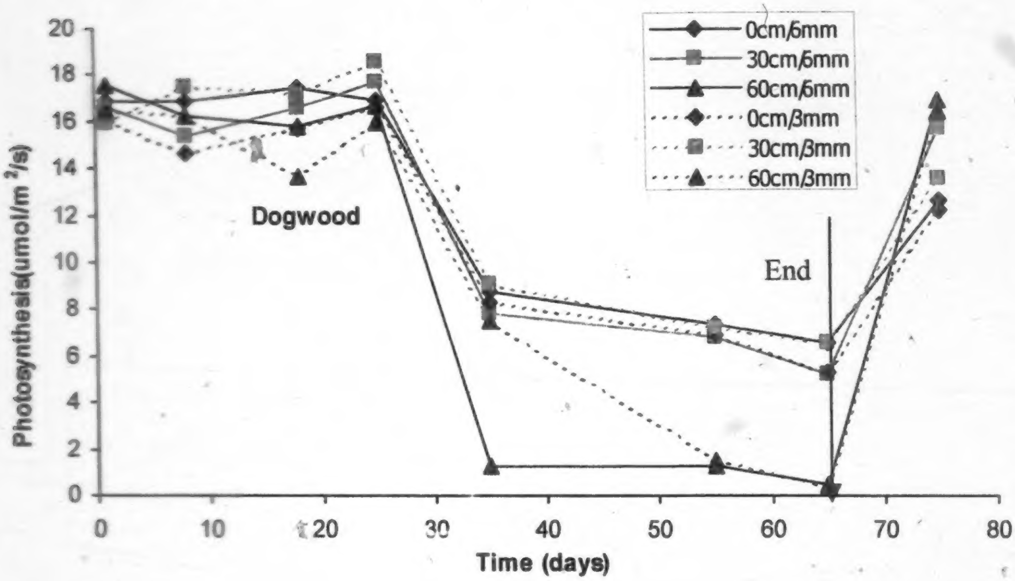


Figure 6.1. Rate of photosynthesis of dogwood and grass in the first drought period. SE for dogwood is 2.87 and that of grass is 1.09.



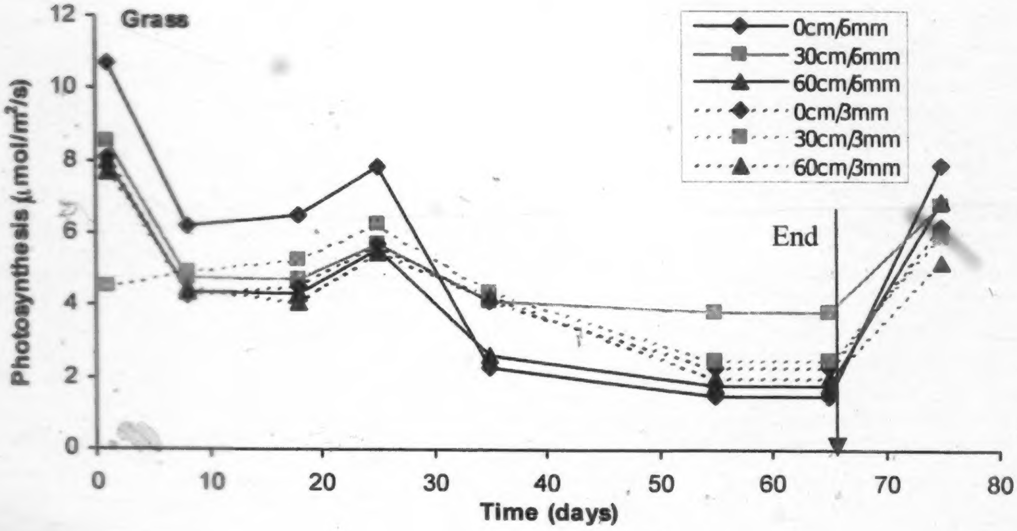


Figure 6.2. Rate of photosynthesis of dogwood and highlander grass leaves under the second drought period. End represents end of the drought period. SE for dogwood is 1.9 and that of grass is 1.02.

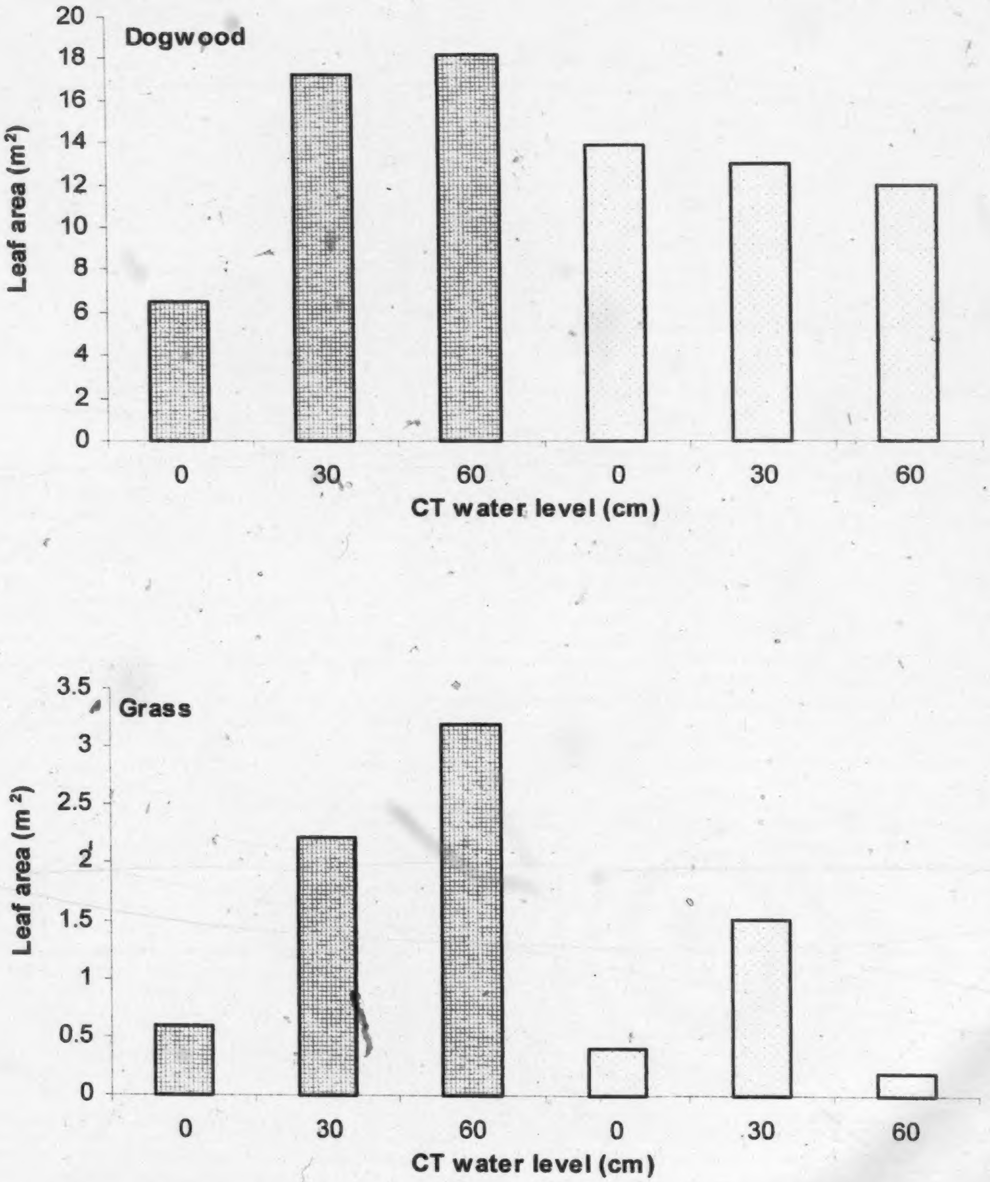


Figure 6.3. Cumulative leaf area of dogwood and highlander grass. Dashed filling is used for high irrigation and dotted filling is used for low irrigation. S.E for dogwood is 1.5 and for grass is 0.35.

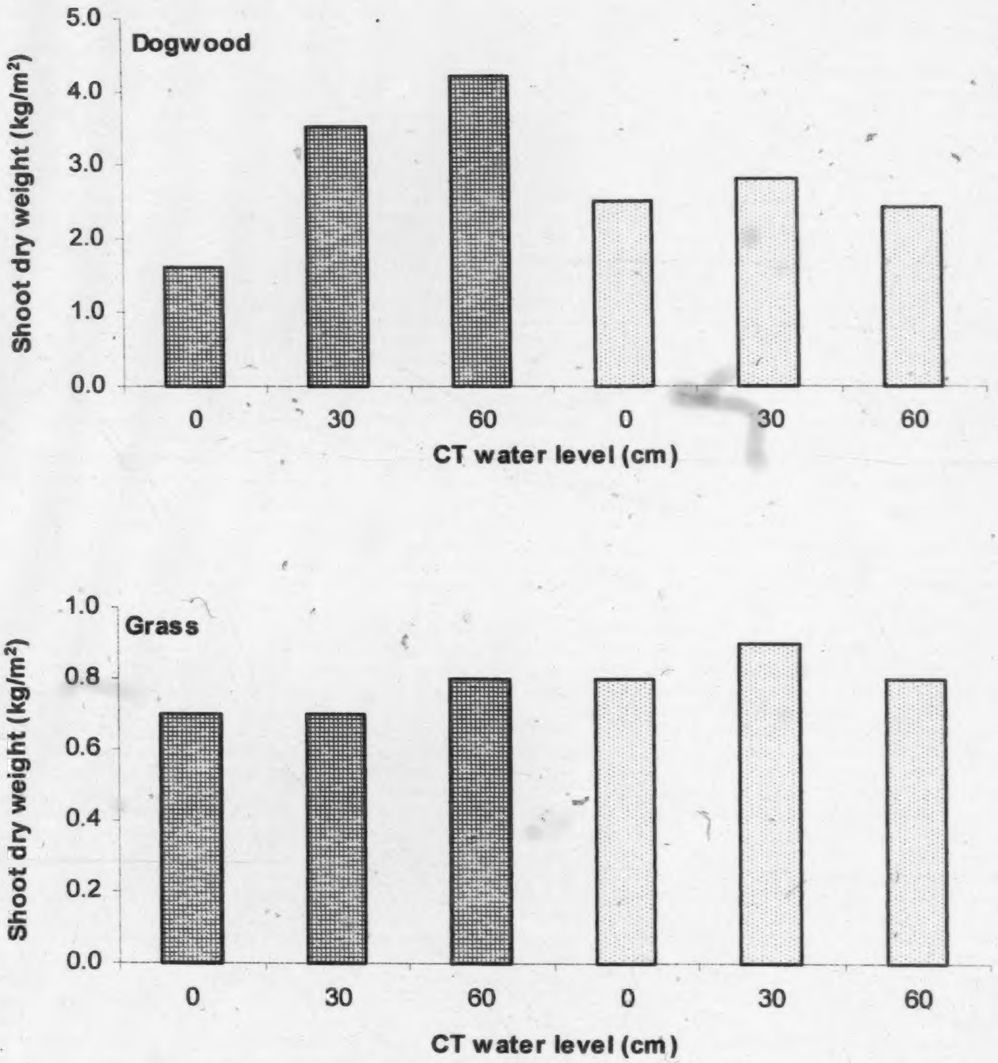


Figure 6.4. Cumulative shoot dry weight of dogwood and grass. Square filling represents high irrigation and dotted filling represents low irrigation. S.E for dogwood is 0.39 and for grass is 0.13.

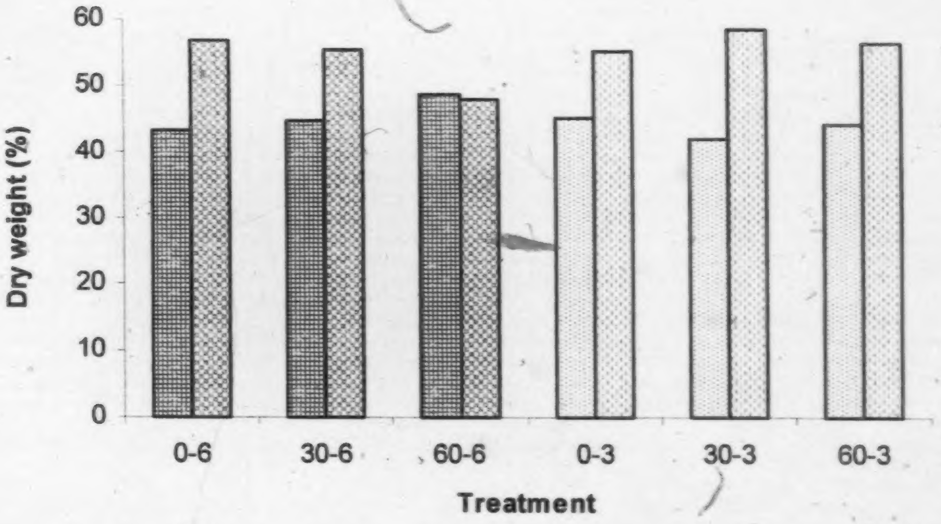


Figure 6.5. Shoot dry weight partitioning of dogwood. Square filling represent leaf dry weight in high irrigation and dotted filling is used for leaf dry weight in low irrigation. Checker filling represents stem dry weight in high irrigation and horizontal filling shows stem dry weight in low irrigation.

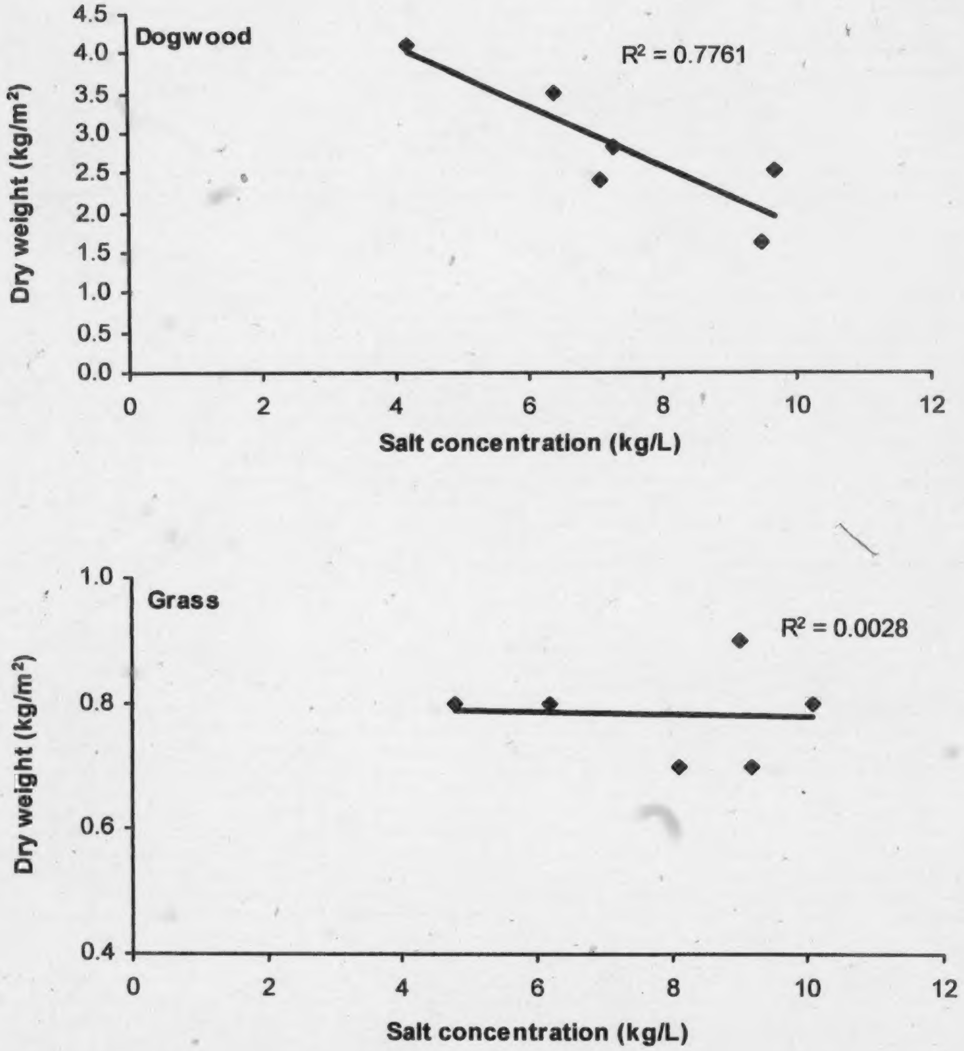


Figure 6.6. Correlation between the shoot dry weight production of dogwood and highlander grass and the accumulated salt concentration in the soil/sand column.

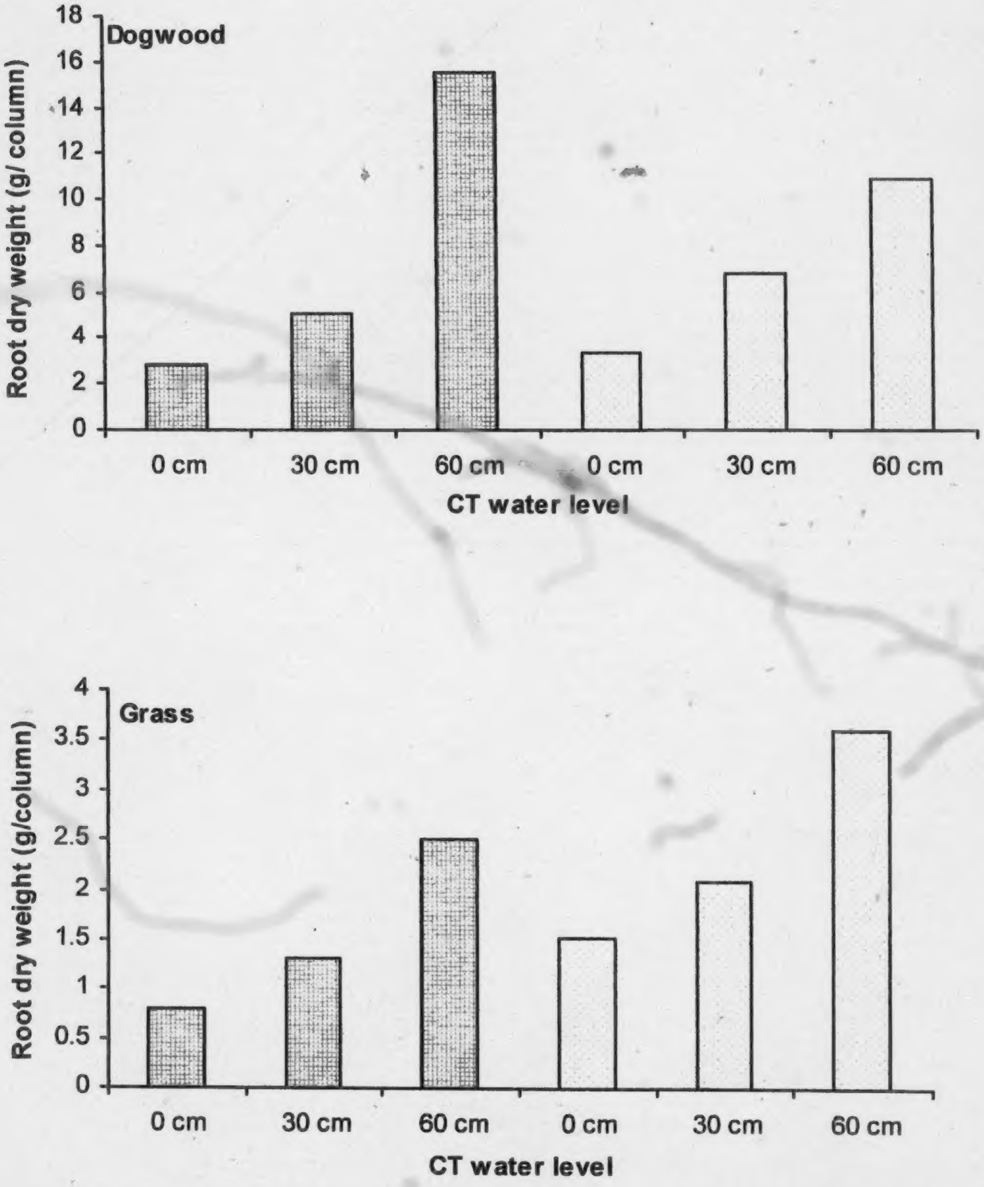
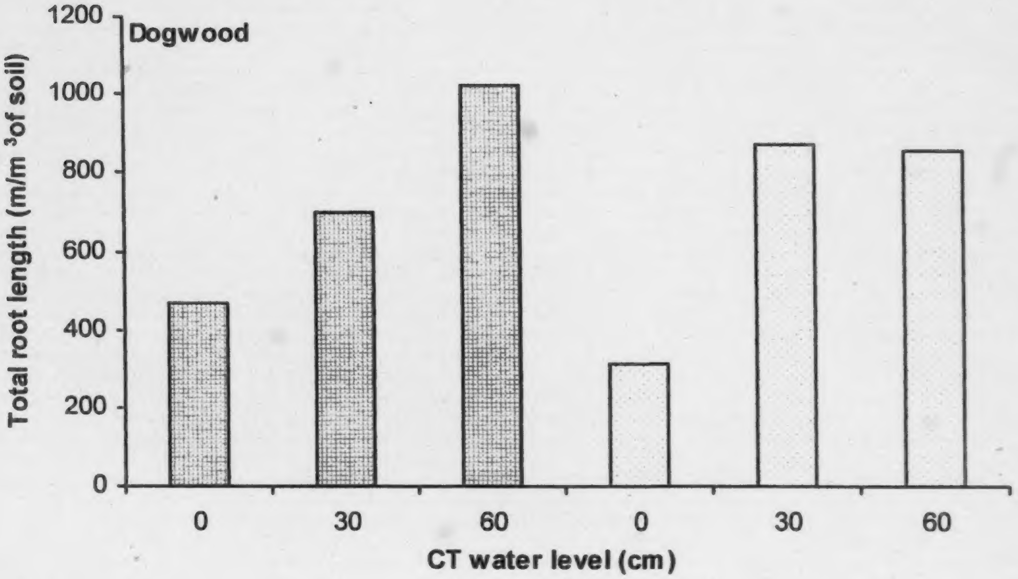


Figure 6.7. Total root dry weight production of dogwood and grass. Square filling represents high irrigation and dotted filling represents low irrigation. SE for dogwood is 1.62 and that of grass is 0.37.



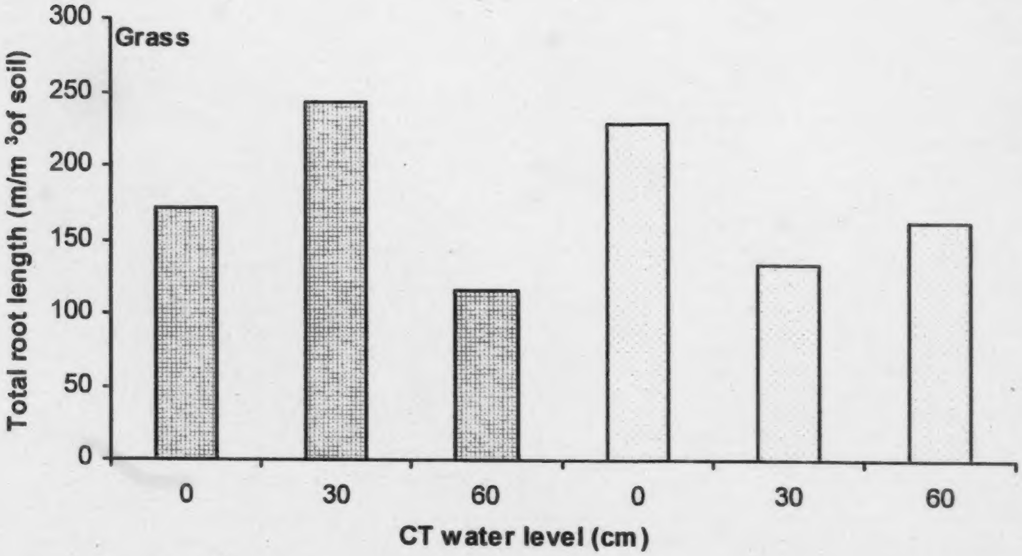
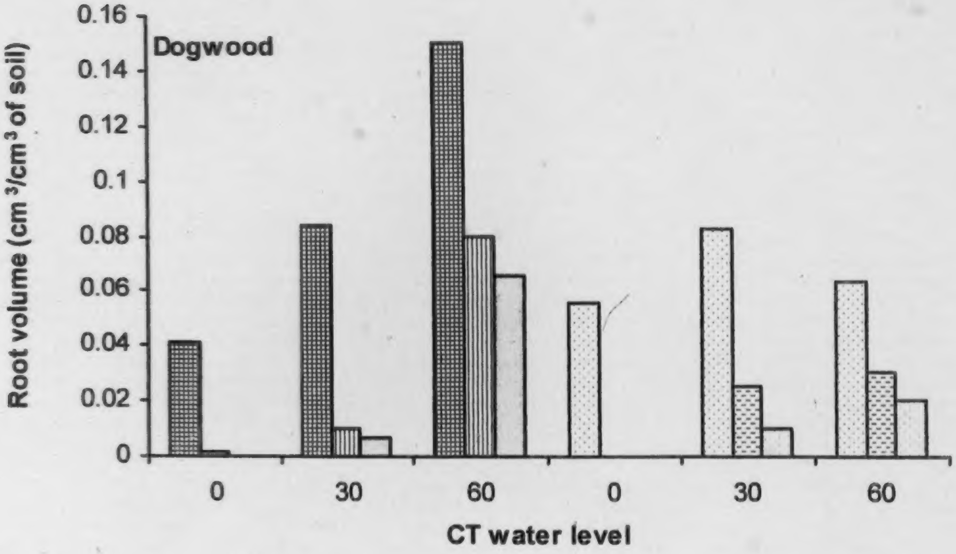


Figure 6.8. Total root length of dogwood and grass in the surface soil of the soil/sand column. Square filling represents high irrigation and dotted filling represents low irrigation. S.E for dogwood is 25.8 and for grass is 15.6.



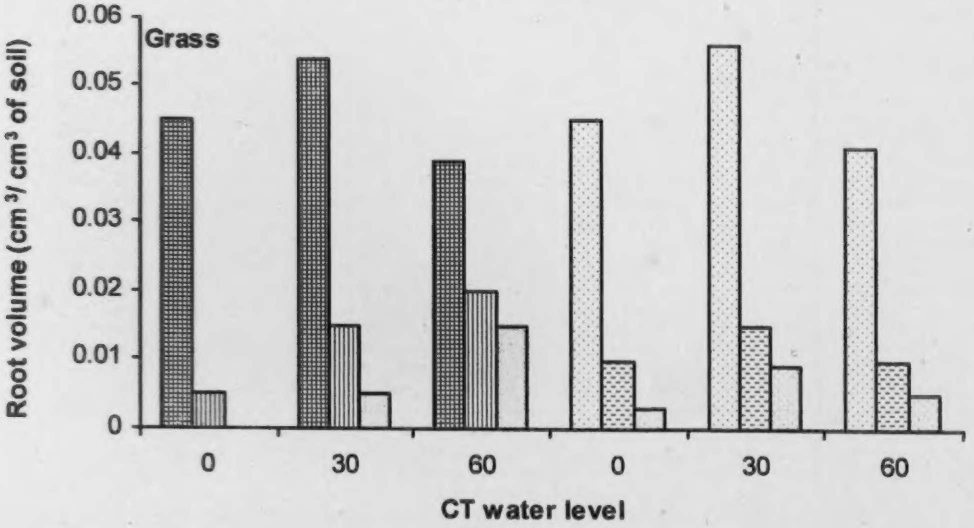
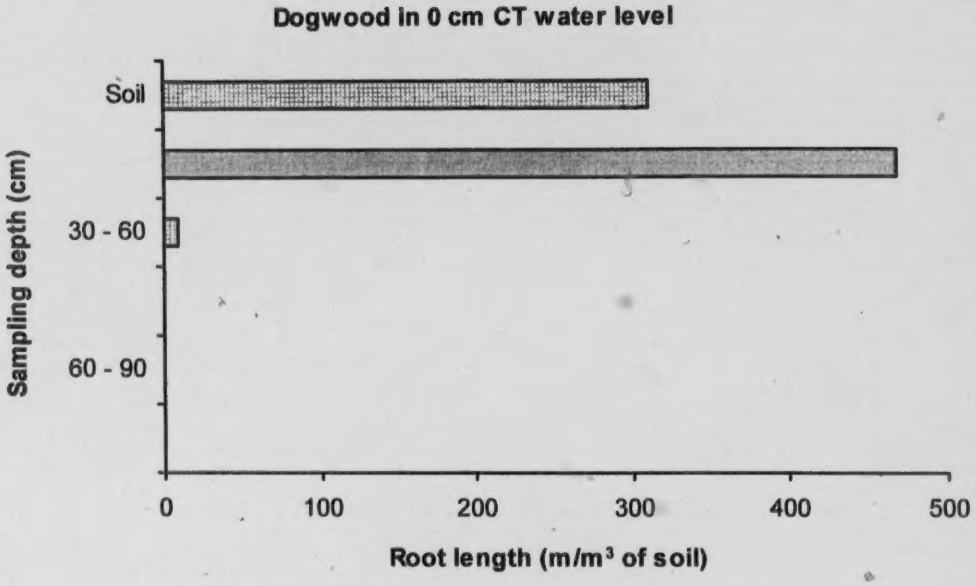


Figure 6.9. Root volume of dogwood and highlander grass. Square filling represents high irrigation and dotted filling represents low irrigation. Second column represent for the middle depth and the third is used for the bottom depth.



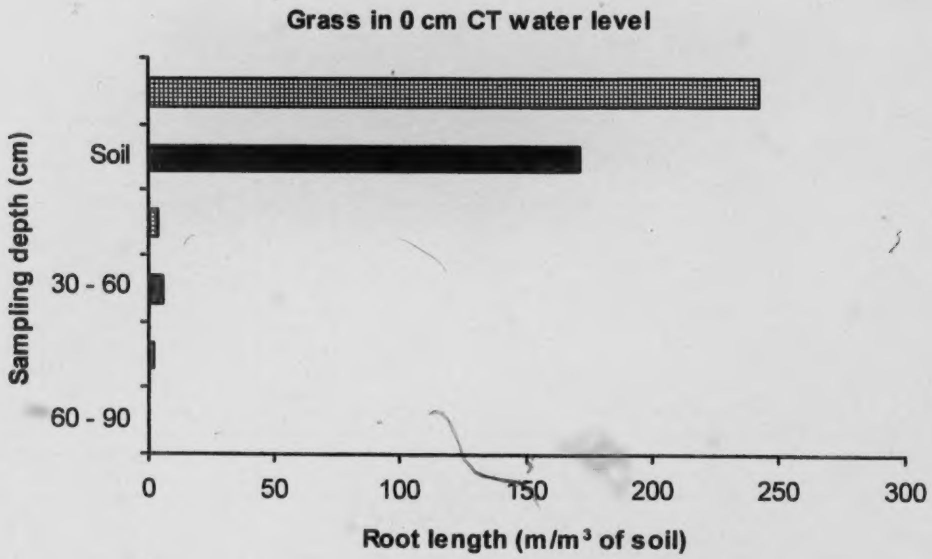
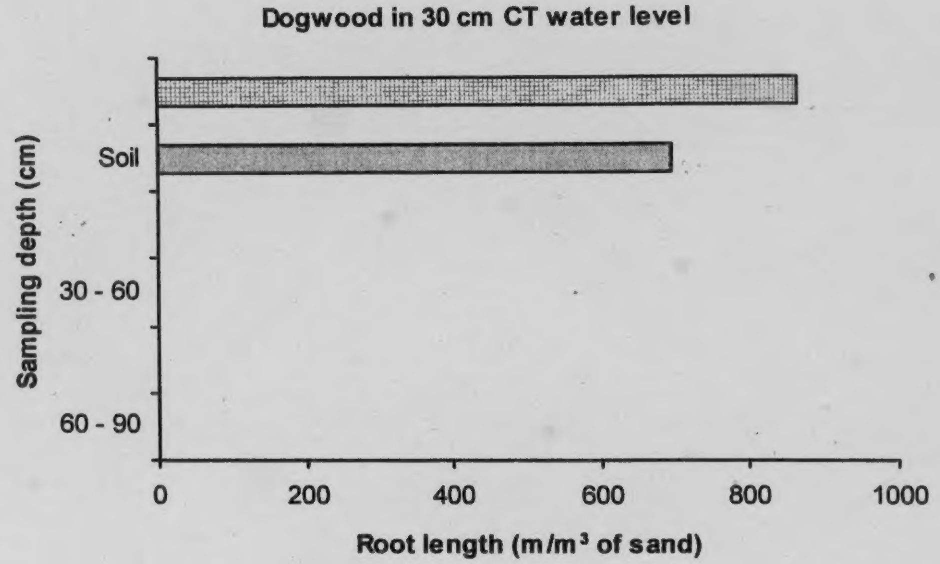


Figure 6.10. Root length distribution of dogwood and highlander grass in the treatment with CT water level at 0 cm. Square filling represents low irrigation, and the solid filling represents high irrigation.



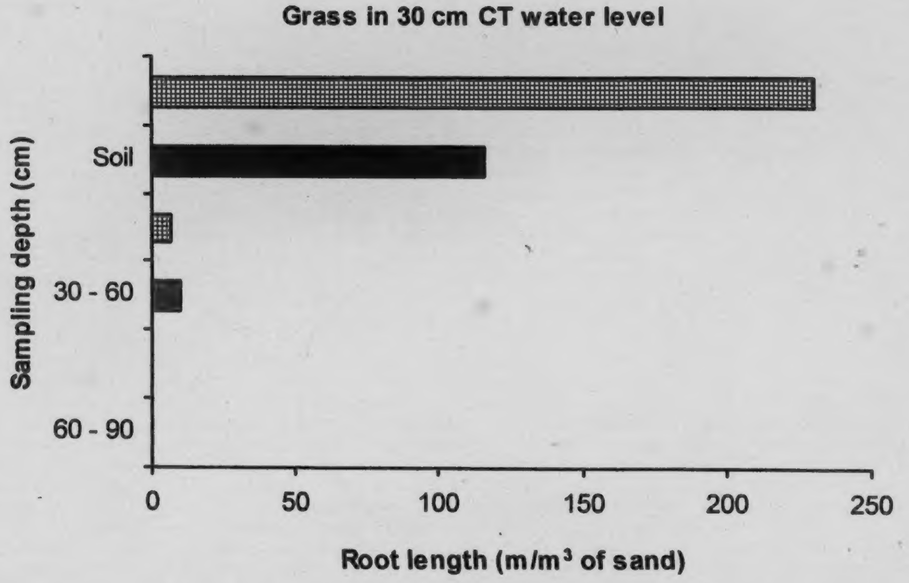
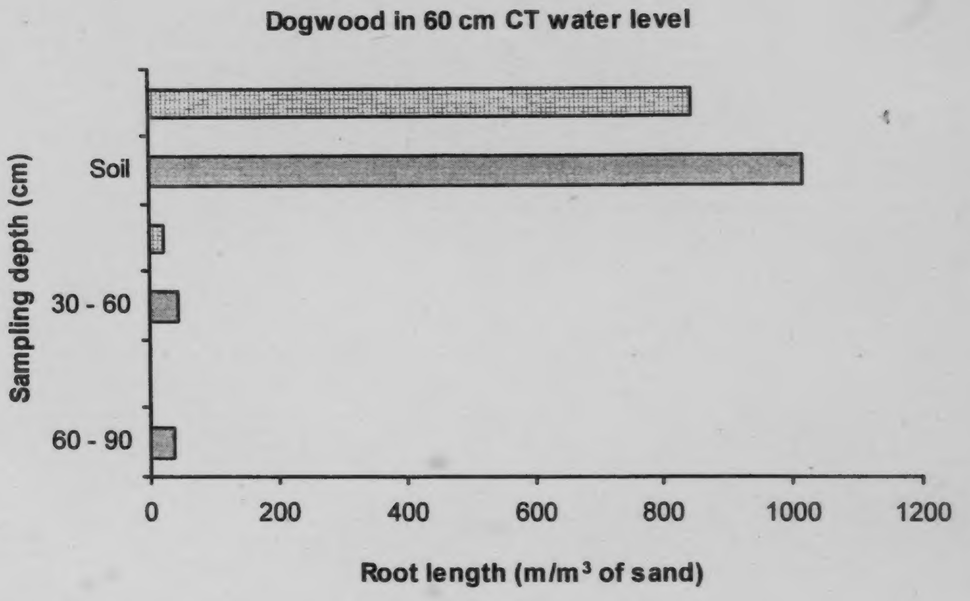


Figure 6.11. Root length distribution of dogwood and grass in the treatment with CT water level at 30 cm. Square filling represents low irrigation, and the solid filling represents high irrigation.



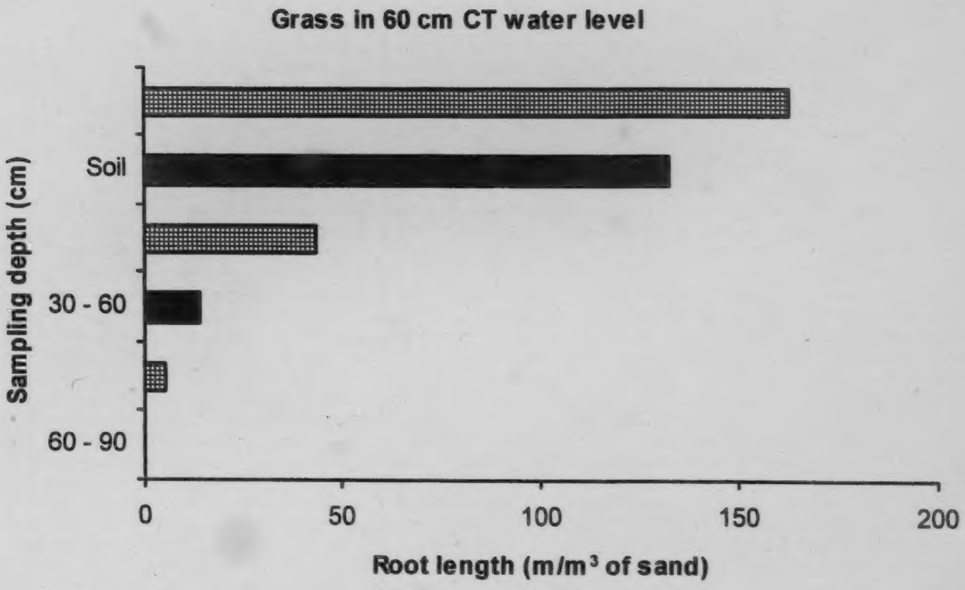


Figure 6.12. Root length distribution of dogwood and grass in the treatment with CT water level at 60 cm. Square filling represents low irrigation, and the solid filling represents high irrigation.

Table 6.1. ANOVA summary for the photosynthesis data of dogwood and highlander grass in the first drought and second drought periods.

Effect Plant	Source	DF	Pr > F Drought Period 1	Pr > F Drought period 2
(Photosynthesis)				
Dogwood	Water table	2	0.3299	0.0118*
	Irrigation	1	0.0448	0.8867
	Water Table*Irrigation	2	0.2385	0.5185
	Day		0.002*	0.0001*
Grass				
	Water table	2	0.8599	0.1405
	Irrigation	1	0.7685	0.0704
	Water Table*Irrigation	2	0.5415	0.4536
	Day		0.51	<0.0001*

* significant at $\alpha = 0.05$

Table 6.2. ANOVA summary for shoot dry weight and root dry weight, root length and root volume of dogwood and highlander grass

Effect	Source	DF	Pr > F
(Shoot dry weight)			
Dogwood	Water level	2	0.014*
	Irrigation	1	0.0349*
	Water level x Irrigation	2	0.0070*
Highlander grass	Water level	2	0.3706
	Irrigation	1	0.2225
	Water Level x Irrigation	2	0.412
(Root dry weight)			
Dogwood	Water level	2	0.0657
	Irrigation	1	0.6983
	Water Level x Irrigation	2	0.1052
Highlander grass	Water level	2	.0732
	Irrigation	1	0.0269*
	Water Level x Irrigation	2	0.7496
(Root length)			
Dogwood	Water level	2	0.0035*
	Irrigation	1	0.5226
	Water level x Irrigation	2	0.2191
Highlander grass	Water level	2	0.2630
	Irrigation	1	0.9498
	Water Level x Irrigation	2	0.0979
(Root volume)			
Dogwood	Water level	2	0.0211*
	Irrigation	1	0.1104
	Water level x Irrigation	2	0.0378*
Highlander grass	Water level	2	0.0211*
	Irrigation	1	0.7515
	Water level x Irrigation	2	0.8891
(Leaf area)			
Dogwood	Water level	2	0.016*
	Irrigation	1	0.065
	Water level x Irrigation	2	0.055
Highlander grass	Water level	2	0.005*
	Irrigation	1	0.002*
	Water level x Irrigation	2	0.0065*

* significant at $\alpha = 0.05$

Table 6.3. Shoot : Root of dogwood and highlander grass

Treatment	Shoot : Root	Treatment	Shoot : Root
Dogwood		Grass	
0cm/6mm	77.74	0 - 6	197.32
30cm/6mm	127.64	30 - 6	139.29
60cm /6mm	49.95	60 - 6	79.47
0cm/6mm	135.63	0 - 3	123.74
30cm/6mm	72.75	30 - 3	103.15
60cm /6mm	38.31	60 - 3	52.43

6.6. References

Ackerson, R. C., and V. B. Youngner, 1975. Responses of bermudagrass to salinity. Agronomy J. 67: 678-681.

Alam, S. M., 1994. Nutrient uptake by plants under stress conditions. 227-246. *In* M. Pessarakli (ed.) *Handbook of Plant and Crop Stress*. Marcel Dekker Inc., New York.

Al-Khafaf, S., A. Adnan, and N. M. Al-Asadi, 1990. Dyanamics of root and shoot growth of barley under various levels of salinity and water stress. Agric. Water Manag. 18: 63-75.

Amor, F. M., M. C. Ruiz-Sanchez, V. Martinez, and A. Cerda, 2000. Gas exchange, water relations, and ion concentrations of salt-stressed tomato and melon plants. J. Plant Nutri. 23: 1315-1325.

Awada, S., W. F. Campbell, L. M. Dudley, J. J. Jurinak, and M. A. Khan, 1995. Interactive effects of sodium chloride, sodium sulfate, calcium sulfate, and calcium chloride on snapbean growth, photosynthesis, and ion uptake. J. Plant Nutri. 18: 889-900.

Bernstein, L., and H. E Hayward, 1958. Physiology of salt tolerance. Ann. Rev. Plant Physiol. 9: 25-46.

Boursier, P., and A. Lauchli, 1990. Growth responses and mineral nutrient relations of salt stressed sorghum. Water Resour. Res. 9: 975-986.

Bresler, E., and G. J. Hoffman, 1986. Irrigation management for soil salinity control: theories and tests. Soil Sci. Soc. Am. J., 50: 1552-1560.

Brugnoli, E., and M. Lauteri, 1991. Effects of salinity on stomatal conductance, photosynthetic capacity, and carbon isotope discrimination of salt-tolerant (*Gossypium hirsutum* L.) and salt-sensitive (*Phaseolus vulgaris* L.) C_3 non-halophytes. Plant Physiol. 95: 628-634.

Cheeseman, J. M., 1998. Mechanisms of salinity tolerance in plants. Plant Physiol. 87: 547-550.

CONRAD, 1998. Naphthenic acids background discussion report. CEATAG Report June 1998. Alberta Department of Energy, Edmonton, Alberta. Canada.

Devine, M., S. Duke, and C. Fedtke, 1993. Physiology of herbicides action. Prentice-hall, Englewood Cliffs, NJ.

Devitt, D. A., D. C. Bowman, and P. J. Schulte, 1993. Response of *Cynodon dactylon* to prolonged water deficits under saline conditions. Plant and Soil, 148: 239-251.

Downton, W. J. S., 1977. Photosynthesis in salt-stressed grapevines. Division of Horticultural Research, CSIRO, Adelaide, S.A.

Downton, W. J. S., 1985. Growth and mineral composition of the sultana grapewine as influenced by salinity and rootstock. Aust. J. Agric. Res. 36: 425-434.

Fine Tailings Fundamentals Consortium, 1995. Advances in Oil Sands Tailings Research, Alberta Department of Energy, Oil Sands and Research Division, Edmonton, Alberta, Canada.

Greenway, H., and R. Munns, 1980. Mechanisms of salt tolerance in nonhalophytes. Ann. Rev. Plant. Physiol. 31: 149-190.

H.B.B.T Limited, 1989. Manual of plant species suitability for reclamation in Alberta. 2nd ed. Rep no. RRTAC89-4. Alberta Land Conservation and Reclamation Council, Edmonton, Alberta.

Hayward, H. E., and W. B. Spurr, 1994. Effects of isosmotic concentrations of inorganic and organic substrates on entry of water into corn roots. Bot. Gaz. 106: 131-139.

Hayward, H. E., and E. M. Long, 1942. Vegetative responses of the Alberta peach on Lovell and Shalil rootstocks to high chloride and sulfate solutions. Am. Soc. Hort. Sci. Proc. 41: 149-155.

Janzen, H. H., and C. Chang, 1987. Cation nutrition of barley as influenced by soil solution composition in a saline soil. Can. J. Soil Sci. 67: 619-629.

Khan, M. G., M. Silberbush, and S. H. Lips, 1994. Physiological studies on salinity and nitrogen interaction in alfalfa. II. Photosynthesis and transpiration. J. Plant Nutri. 17: 669-682.

Kramer, P. J., and T.T. Kozlowoski, 1997. The Physiology of woody plants. Academic Press. New York.

Lamsal, K., N. P. Guna, and M. Saeed, 1999. Model for assessing impact of salinity on soil water availability and crop yield. Agric. Water Manag. 41: 57-70.

MacKinnon, M. D., J. G. Matthews, W. H. Shaw, and R. G. Cuddy, 2000. Water quality issues associated with implementation of composite tailings (CT) technology for managing oil sands tailings. Proceedings of the Sixth International Conference on Environmental Issues and Management of Waste in Energy and Mineral Production (SWEMP 2000) Calgary, Alberta. 443-453.

Marcelis, L.F.M., and J. Van Hooijdonk, 1999. Effect of salinity on growth, water use and nutrient use in radish (*Raphanus sativus* l.). Plant and Soil. 215: 57-64.

Marler, T. E., and Y. Zoror, 1996. Salinity influences on photosynthetic characteristics, water relations, and foliar mineral composition of *Annona squamosa* L. J. Am. Soc. Hort. Sci. 12: 243-248.

Mass, E.V., and G. J. Hoffmann, 1977. Crop salt tolerance- Current Assesment. J. Irri. Div. Proc. Am. Soc. Civ. Eng. 103 (IR2): 115 - 134

Meiri, A., and A. Poljakoff-Mayber, 1969. Effect of various salinity regimes on growth, leaf expansion and transpiration rate of bean plants. Soil Sci. 109:26-34.

Mickelbart, M. V., and T. E. Marler, 1996. Root-zone sodium chloride influences on photosynthesis, water relations, and mineral content of sapodilla foliage. Hort. Sci. 31: 230-233.

Mikula, R. J., K. L. Kasperski, R. D. Burns, and M. D. MacKinnon, 1996. Nature and fate of oil sands fine tailings. 677-723. *In*: Schramm, L.L. (ED.) *Suspensions: fundamentals and applications in the petroleum industry*. American Chemistry Society Publication, Washington.

Neumann, P. M., H. Azaizeh, and D. Lean, 1994. Hardening of root cell walls: a growth inhibitory response to salinity stress. Plant Cell Environ. 17: 303-310.

Noggle, G. R., and G. J. Fritz, 1983. Introductory Plant Physiology. Prentice-hall, Englewood Cliffs, NJ.

Passioura, J. B., 1988. Water transport in and to roots. Annu. Rev. Plant Physiol. Plant Mol. Bio. 39: 245-265.

Pearcy, R.W., and S. L. Ustin, 1984. Effects of salinity on growth and photosynthesis of three California tidal marsh species. Oecologia. 62: 68 - 73.

Renault S., C. Croser, J. A. Franklin, and J. J. Zwiazek, 2001. Effects of NaCl and Na_2SO_4 on red osier dogwood (*Cornus stolonifera* Michx) seedlings. Plant and Soil. 233: 261-268.

Renault, S., C. Lait, J. J. Zwiazek, and M. MacKinnon, 1998. Effect of high salinity tailings waters produced from gypsum treatment of oil sands tailings on plants of the boreal forests. Environ. Pollution. 102: 177-184.

Renault, S., E. Paton, G. Nilsson, J. J. Zwiazek, and M. D. MacKinnon, 1999. Responses of boreal plants to high salinity oil sands tailings water. J. Environ. Qual. 28: 1957-1962.

Robbins, C. T., and A. N. Moen, 1975. Composition and digestibility of several decidous browses in the northeast. J. Wild. Manag. 39: 337-341.

Rozema, J., 1991. Growth, water and ion relationships of halophytic monocoteledonae and dicotylednae; a unified concept. Aquat. Bot. 39: 17-33.

SAS Institute Inc., 1990. SAS users guide: statistics. SAS Institute Inc., Cary, N.C.

Seeman, J. R., and C. Critchley, 1985. Effects of salt stress on the growth, ion content, stomatal behaviour and photosynthetic capacity of a salt sensitive species, *Phaseolus vulgaris* L. Planta. 164: 151-162.

Sego, D. C., S. A. Proskin, and R. Burns, 1993. Enhancement of solid content of oil sands fine tails by chemical treatment and freeze thaw. Proceedings of the 46th Canadian Geotechnical Conference, April 4-7, 1993. Saskatoon, Saskachewan, Canada. 392-400.

Stewart. J.I., R. E. Danielson, R. J.Hanks, E. B. Jackson, R. M. .Hagan, W. O. Pruitt, W. T. Franklin, and J. P. Riley, 1977. Optimizing crop production through control of water and salinity levels in the soil. Utah Water Lab. PRW 6-161-1.

Ullah, S. M., G. Soja, and M. H. Gerzabek, 1993. Ion uptake, osmoregulation and plant water relations in faba beans (*Vicia faba* L.) under salt stress. Bodenculture 44: 291-301.

Wadleigh, C. H., and H. G. Gauch, 1944. The influence of high concentrations of sodium sulfate, sodium chloride, calcium chloride, and magnesium chloride, on the growth of guayule in sand culture. Soil Sci. 58: 399-403.

Walker, R. R., D. H. Blackmorg, and S. Qing, 1993. Carbon dioxide assimilation and foliar ion concentrations in leaves of lemon (*Citrus limon* L.) trees irrigated with NaCl or Na_2SO_4. Aust. J. Plant Physiol. 20: 173-185.

Chapter - 7

Synthesis

Reclamation of CT can be hampered by high concentration of NaCl and Na_2SO_4, flooding, and anaerobic conditions (Renault et al., 1998: Croser and Zwiazek, 2000). Nonetheless, production of CT is preferable to the alternative of continued accumulation and perpetual storage of fine tailings (Sheeran, 1993). One of the possible reclamation technologies for revegetation on reclaimed CT is the capping technology developed by MacKinnon (2000), in which tailings materials are capped with the coarser tailings sand and reclamation material. In this technology, sand cap is used as a capillary barrier for the CT water released from the CT after its self-weight consolidation. The main objective of this research was to determine the minimum thickness of the sand cap separating CT water and surface soil (Figure 1.3).

Dogwood and highlander grass were grown in columns in a growth chamber. Each column (100 cm height and 56 cm diameter) was filled with tailings sand (bottom 65 cm) and reclamation material (top 30 cm). Four suction lysimeters were inserted at 4 different depths. The treatments consisted of three CT water levels (0, 30, 60 cm from the top of the soil/ sand interface). Two irrigation rates, 3 mm/application (low) and 6 mm/application (high) were used to simulate dry and wet conditions respectively. Dogwood received water every alternate day and highlander grass received water every third day. The experiment was run under two drought periods by withholding irrigation water in order to monitor the salt migration and survival of the two plant species. The first, shorter, was run for 16 days and the, longer, was run for 66 days.

Movement of salt in the soil/sand profile was monitored by measuring the electrical conductivity of the soil pore water extracted using the suction lysimeters. Salt accumulation at the end of the experiment was determined from the EC in the soil profile. Performance of plants was determined by measuring plant water potential, osmotic potential, photosynthesis, above ground dry weight, root dry weight, root length, root volume, and leaf area.

7.1. Major findings

Salts from the CT water did move up in the soil/sand column by capillary rise in all treatments (Chapter 4). Most accumulated salt from the CT water remained at the bottom of the column. Treatment with highlander grass showed more upward migration of salt than those with dogwood. In Highlander grass, salt from the CT water level at 30 cm depth moved up to the surface soil (EC of pore water > EC of CT water). CT water level at 60 cm depth seemed to prevent salt accumulation in the surface soil. Results from this study indicate an inverse relationship between the irrigation rate and salt accumulation in the soil profile. In all treatments, low irrigation resulted in greater accumulation of salt, particularly if the depth of CT water level is at 0 cm. Accumulation of salt in the soil profile increased under drought condition.

Salt accumulation in the soil profile is related to CT water use by the plants, and evaporation from the soil surface. Treatment with dogwood showed a poor correlation between the total amount of CT water consumed by evapo-transpiration and the total amount of salt accumulated in the column ($R^2 = 0.34$), whereas treatment with highlander grass showed a strong relationship ($R^2 = 0.74$). The difference in the response of salt accumulation by these two plant species might be due to the fact that grasses were cut several times during the experiment, leaving bare surface, and therefore increasing the evaporation rate (Nobel, 1996). Dogwood was only pruned.

Salt in the soil solution reduces the soil water potential by developing osmotic potential. The reduction in soil water potential restricts water uptake by plant roots, thereby decreasing plant water potential (Greenway and Munns, 1980). In response to decrease in plant water potential, plants reduce their osmotic potential to maintain turgor and growth (osmotic adjustment). Increased salt concentration reduced the leaf water potential and osmotic potential significantly, especially during the long drought period. Reduction in leaf osmotic potential was in response to the reduced plant water potential, indicating osmotic adjustment. Both dogwood and highlander grass tolerated increased salt concentration in the soil water by reducing their osmotic potential, and maintained their turgor.

Reduction in photosynthesis rate was observed only after water potential and osmotic potential started decreasing, suggesting that reduction in photosynthesis is due to osmotic effect. The CT water level depth and irrigation rate significantly affected above ground dry matter of dogwood, however, root dry mater was unaffected. Highlander grass showed the opposite response to CT water level and irrigation on shoot dry weight and root dry weight. Shoot dry weight of highlander grass was unaffected by CT water level depth and irrigation, whereas root dry weight was affected, suggesting the two plant species responded differently under saline condition. However, this needs further research to confirm this finding.

7.2. Implications

Results from this study suggest that CT water level should not be less than 60 cm from soil /sand interface. However, there may be negative implications if CT water level is maintained at greater depth, particularly for the survival and growth of plants during severe drought. These are findings based on growth chamber studies. Under field conditions, this may change because of variable climate and topography. The conclusion that there is an "optimum" CT water depth, which prevents the negative impacts of salt accumulation in the soil profile, and at the same time allows plants to utilize CT water during severe drought, however, is expected to be valid for field conditions.

Plant response to drought condition was not evident until day 25 in to the drought period, indicating the tolerance level of the two plant species using moisture reserve in the soil. Low irrigation caused greater reduction in water potentials of both the plant species than high irrigation. Results from photosynthesis analysis also suggest that these two plant species can perform well for two weeks without receiving irrigation water. However, the duration of draught tolerance may change under field conditions, which should be studied.

The importance of quantity and frequency of irrigation water has practical implications. This research suggests that the depth of CT water level should be at least 60 cm. However, at low CT water level (below 60 cm), survival of plants, especially under drought condition may be a concern because of the unavailability of moisture. On the other hand, high CT water level will result in more accumulation of salt, which inhibits plant growth (Croser et al., 2001; Grenway and Munns, 1980; Renault et al., 2001; Brugnoli and Lauteri, 1991). Another factor, which should be considered in determining the depth of CT water level, is the topography. In the field, due to uneven topography, presence of recharge and discharge zones will play a role in salt movement and accumulation.

7.3. Recommendation

Based on the salt movement in the soil profile and response of dogwood and highlander grass in terms of their dry matter production, it is recommended that the capping thickness between the soil layer and the CT water table should not be less than 60 cm. However, several factors should be considered in implementing the results of this study to predict the most suitable depth of CT water under field conditions. These experiments were conducted in a controlled environment, under constant environmental conditions, and with adequate nutrient supply (fertilizer). The interactions between salinity and environmental factors are important, but are beyond the scope of this research. Finally, these experiments were relatively short in duration and extrapolation into field condition should be done with caution.

The main concern for the reclamation is salinity originated from the saline CT water. Salinity increases over time as soil water is selectively taken up by plant roots and evaporates at the soil surface. The problem of salinity worsens under drought condition as plants take up CT water. Under the conditions of this study, dogwood and highlander grass can tolerate the drought for up to 25 days without having negative impact on their water potential, and photosynthesis rate, and can survive the drought period of two months when CT water is within reach of the roots.

7.4. Future study

CT water has been found to contain boron at a concentration of 3.5 mg/L (Renault et al., 1999), which could aggravate the salinity effect and hamper the plant growth. Effect of heavy metal and other organic compound (naphthenic acid) present in CT water, on plant growth needs to be studied. Maintenance of CT water level at constant level in field can pose a major challenge. A small-scale field study should be conducted to predict the most suitable CT water level depth before implementing the results from this study to a large area. Role of varying climatic conditions and topography on salt movement from the saline CT water into the soil profile, and its effect on the growth of dogwood and highlander grass should be investigated. Effect of long severe winter on salt movement needs to be studied, as freezing and thawing of CT water may affect salt accumulation.

7.5. References

Brugnoli, E., and M. Lauteri, 1991. Effects of salinity on stomatal conductance, photosynthetic capacity, and carbon isotope discrimination of salt-tolerant (*Gossypium hirsutum* L.) and salt-sensitive (*Phaseolus vulgaris* L.) C_3 non-halophytes. Plant Physiol. 95: 628-634.

Croser, C., and J. J. Zwaiazek, 2000. The effect of alum and gypsum consolidated tailings on the survival, growth and mineral composition of dogwood (*Cronus stolonifera*) and raspberry (*Rubus idaeus*). Dept. of Ren. Res. University of Alberta, Edmonton, Canada. Report compiled for Syncrude Canada Ltd.

Croser, C., S. Renault, J. Franklin, and J. J. Zwaiazek, 2001. The effect of salinity on the emergence and seedling growth of *Picea mariana*, *Picea glauca*, and *Pinus banksiana*. Environ. Pollution. 115: 9-16.

Greenway, H., and R. Munns, 1980. Mechanisms of salt tolerance in nonhalophytes. Ann. Rev. Plant. Physiol. 31: 149-190.

MacKinnon, M. D., J. G. Matthews, W. H. Shaw, and R. G. Cuddy, 2000. Water quality issues associated with implementation of composite tailings (CT) technology for managing oil sands tailings. Proceedings of the Sixth International Conference on Environmental Issues and Management of Waste in Energy and Mineral Production (SWEMP 2000) Calgary, Alberta, Canada. 443-453.

Nobel, P.S., 1996. Physiochemical and Environmental Plant Physiology. Academic Press, San Diego, California.

Renault, S., C. Lait, J. J. Zwiazek, and M. MacKinnon, 1998. Effect of high salinity tailings water produced from gypsum treatment of oil sands tailings on plants of the boreal forests. Environ. Pollution. 102: 177-184.

Renault, S., E. Paton, G. Nilsson, J. J. Zwiazek, and M. D. MacKinnon, 1999. Responses of boreal plants to high salinity oil sands tailings water. J. Environ. Qual. 28: 1957-1962.

Renault S., C. Croser, J. A. Franklin, and J. J. Zwiazek, 2001. Effects of NaCl and Na_2SO_4 on red osier dogwood (*Cornus stolonifera* Michx) seedlings. Plant and Soil. 233: 261-268.

Sheeran, D. E., 1993. An improved understanding of fine tails structure and behaviors. Proceedings of Oil Sands - Our Petroleum Future Conference. Fine Tails Fundamentals Consortium. April 4-7, 1993, Edmonton.

APPENDIX A1

Sample Calculations

Electrical conductivity analysis by conductivity bridge meter (Chapter 3 and Chapter 4)

Sample calculation for one sample, number in the table 4.1 is the average of 4 samples

Standard (KCl solution) = 0.82 µmho * 1000 = 820 µmho
Conductivity at room temperature (23°C) = 1326.6 µmho (Conductivity bridge meter manual)
Factor = 1326.6/ 820 = 1.66 µmho
Conductivity of CT water = 2.5*1000 µmho = 2500* 1.66 = 4150 µmho
= 4150 µmho/1000 = 4.15 dS/m

Total amount of salt in the soil/sand column (Chapter 3 and Chapter 4)

(a) Gravimetric water content (θ_m) Calculation

Sample			Subsample		
Weight (g)	Volume (cm^3)	Water content (g)	Weight (g)	Oven dry weight (g)	Water content (g)
1208	1000	841.5	42.28	12.83	29.45

ρb = Samples dry weight/samples volume
= (1208 – 841.5) g/1000 cm^3
= 0.37 g/ cm^3

θ_m = Moisture present/dry wt.
= 841.50/366.60 = 2.29

θ_v = θ_m x ρb
= 2.29 x .37
= 0.85

(b) Calculation of EC by Saturation Paste Extract Method

$\theta_m = 2.29$
$V_{wsp} = 49.75$ g
D.F. = V_{wsp} / (Subsample's dry weight x θ_m)
= 49.75/ (12.83 x 2.29)
= 1.69

EC $_{pw}$ = EC_{sp} x D.F.
= 2.82 x 1.69
= 4.76 dS/m

(c) Calculation of Salt concentration in the column

Salt Conc. in the soil layer = EC_{pw} x 640 x θ_v x depth of the soil layer
= (4.76 x 640 mg x 0.84 x 30 cm) / 1L x 1000 cm^3
= 76.77 mg/cm^2

Salt Conc. between 30 cm and 60 cm below the interface
= $(EC_{(30)} + EC_{(60)})/2$ x 640 x θ_v x depth
= (3.65 + 4.93)/2 x 640 x 0.47 x30
= 38.71 mg/cm^2

Salt Conc. between 60 cm and 90 cm below the interface
= $EC_{(60)}$ x 640 x θ_v x depth
= 4.93 x 640 x 0.51 x 30
= 48.27 mg/cm^2

Total salt accumulated in the soil/sand column
= $C_{soil} + C_{30} + C_{60}$
= 76.77 + 38.71 + 48.27 mg/cm^2
= 1637.5 g/m^2
= 1.637 kg/m^2

Salt content in the soil sand column
= 1.637 kg/m^2 x area of the column
= 1.637 kg/m^2 x 3.14 x 0.28 x 0.28 m^2
= 0.403 kg
